Diet and Control Squads and Investigators, International Young Men's Christian Association College, Springfield, Massachusetts, January 11, 1918.

Control Squad (B) top row, standing: Livingstone, Williams, Kimball, Thompson, Long, Hammond, Van Wagner, Hartshorn, Howland, Fisher, Snell, Schrack. (McMichael absent.)

Low-diet Squad (A), middle row, standing: Gullickson, Gardner, Moyer, Canfield, Veal, Peckham, Peabody, Montague, Brown. (Spencer, Tompkins, and Kontner absent.)

Investigators, sitting: Emmes, Miles, Smith, Roth, Benedict, Berry, Johnson, Fox.

HUMAN VITALITY AND EFFICIENCY UNDER PROLONGED RESTRICTED DIET

BY

FRANCIS G. BENEDICT, WALTER R. MILES, and others

PAUL ROTH, AND H. MONMOUTH SMITH

PUBLISHED BY THE CARNEGIE INSTITUTION OF WASHINGTON

WASHINGTON, 1919

(Nutrition Laboratory)

CARNEGIE INSTITUTION OF WASHINGTON
PUBLICATION No. 280

PRESS OF GIBSON BROTHERS, INC.
WASHINGTON, D. C.

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HUMAN VITALITY AND EFFICIENCY UNDER PROLONGED RESTRICTED DIET

BY

Francis G. Benedict, Walter R. Miles, Paul Roth, and H. Monmouth Smith

INTRODUCTION.

For many years the Nutrition Laboratory has been studying the possibility of variations in nutritional levels, searching more especially for individuals or classes of individuals with a noticeably low metabolism. To this end evidence has been sought in experiments with a man having but one lung; with individuals claiming to subsist upon considerably less food than an ordinary individual; with vegetarians; with a man fasting for a period of 31 days; and with diabetic patients undergoing the Allen fasting treatment and subsequent low diet. None of these researches, however, gave definite evidence of a low metabolism except those carried out under the somewhat abnormal conditions of a complete fast and severe diabetes.

While the regular accumulation of experimental data regarding basal metabolism has proceeded unabated, the establishment or the discovery of subnormal metabolism was less accentuated since only negative results had previously been obtained. Recently, however, international complications, causing great food stringency in different parts of the war region, have again called our attention to the problem of low metabolism and undernutrition.

The tremendous efforts of the Central Powers of Europe to withstand the food blockades of their opponents resulted in a most surprising development of food substitutes, many of these being prepared from materials formerly used for stock feeding. A complete economic system was thus developed to secure the proper distribution and rationing of the various food materials. Notwithstanding this use of unusual foodstuffs, the rations of the civilian population of Germany were severely curtailed. Most of the early information as to dietetic conditions in Germany, which can be considered as having scientific merit, was brought to this country by Professor Alonzo E. Taylor, formerly assigned to the United States embassy in Berlin. The statistical evidence which he secured in Berlin through his office, by the cooperation of Dr. E. Rost of the Gesundheitsamt and of Professor Rubner, and from innumerable ration cards, shows that the Central Powers as a whole were compelled, on account of war conditions, to adopt a materially lowered ration. This gigantic experiment proves conclusively that such changes are not only possible, but are not necessarily cataclysmic. They therefore challenge the scientific world for explanation.

As compensatory consequences of ration curtailment, only a general loss in body-weight is reasonably demonstrated. Statistically this hardly seems proportional to the diet curtailment, and evidence regarding a possible general reduction in physical activity is absent.

Furthermore, there is lacking that careful scientific balance which is necessary to demonstrate an actual lowering of the metabolism to compensate, in part at least, for the lower food-intake. It appeared to us that if the German civilian population had found it possible under war conditions to subsist on these low rations and had apparently adjusted themselves to an entirely new and heretofore practically unrecognized nutritional level, the scientific foundation for this change was certainly worthy of exact study. Furthermore, such research seemed especially timely, as the attention of a large number of American people was, in 1917, directed towards the conservation of food; it was accordingly important to analyze critically the factors that play the chief rôle in such conservation. Strenuous efforts had been made to reduce the consumption of certain food materials, such as sugar, wheat products, and animal products, by advocating the substitution of other materials, but one factor had previously been for the most part neglected, *i. e.*, the possibility of a reduction in the amount of food consumed. The general problem of reducing the total food consumption quantitatively could not, however, be seriously considered by the laity. In view of the emergency confronting this nation in 1917, it was natural that the importance of food conservation should likewise occupy the minds of practically all physiologists. The question therefore arose with the Nutrition Laboratory: Is it possible by any dietetic régime to lower the total amount of food consumed and not at the same time disproportionately lower efficiency for either intellectual or muscular activity? In other words, is it possible to make a dietetic alteration of material moment which will still enable individuals to carry on their general activities, both intellectually and physically, as members of society, without appreciable detriment?

It has not been the custom of the Nutrition Laboratory to direct its researches primarily for economic and sociological purposes; yet in view of its long-continued study of people with a low intake of food and conceivably low metabolism, and the not remote possibility that America might be obliged to undergo privations similar to those in Germany, although probably in less degree, it seemed eminently fitting for the Laboratory to study a question so important from the standpoints of patriotism, economy, and physiology, as the effect upon the metabolism of a reduction in diet. The extensive research which is reported in this publication is, in the last analysis, a furthering of the initial problem studied by the Nutrition Laboratory, *i. e.*, a search for conditions resulting in subnormal metabolism. It was planned in detail in the spring of 1917 and carried out during the winter of 1917–18 with a selected group of normal individuals whose body-weight was lowered as a result of quantitative reductions in their diet.

Before giving the details and discussing the results of this research, a general history will be given of the experimental work leading up to the present study, together with brief abstracts and a critique of the work of other investigators on metabolism with a low intake of food.

SEARCH FOR SUBNORMAL METABOLISM.

The initial experiments in the study of variations in basal metabolism were carried out at Wesleyan University, Middletown, Connecticut, with several subjects who seemed to show potentialities for low metabolism. The first study was that of a man who had but one lung,[1] the assumption being made that with diminished lung area there might be distinctly different metabolic activity. The results of this experiment, although perhaps somewhat open to debate when judged by modern technique and compared with modern data, indicated no striking change in the level of metabolism.

From time to time during the past two decades certain individuals, particularly those who have given more than ordinary attention to their dietetic habits, have come forward with the contention that they were able to subsist upon considerably less food than is required by the normal individual. The first one studied was the case of the late Mr. Horace Fletcher. Mr. Fletcher had interested himself in sociological and economic problems for a number of years and had brought himself to believe that by means of a peculiar adjustment of diet and particularly a supposedly advantageous method of excessive mastication, he could subsist upon materially lower amounts of food and with a much lower metabolism than normal individuals. His contention was seemingly supported by the observations of Professor Chittenden,[2] of Yale University. While the observations on Mr. Fletcher dealt primarily with the total nitrogen metabolism, Professor Chittenden, in commenting upon the excessive muscular work done, makes the following statement regarding the energy transformation:

"Yet the work was done without apparently drawing upon any reserve the body may have possessed. The diet, small though it was, and with only half the accepted requirement in fuel value, still sufficed to furnish the requisite energy. The work was accomplished with perfect ease, without strain, without the usual resultant lameness, without taxing the heart or lungs, and without loss of body-weight. In other words, in Mr. Fletcher's case at least, the body machinery was kept in perfect fitness without the consumption of any such quantities of fuel as has generally been considered necessary."[3]

In other words, on the low energy intake of approximately 1,700 calories Mr. Fletcher, carrying out the training régime and exercises of the Yale University crew, was able to perform a day's duty of this type with supposedly no draft upon body material.

[1] Carpenter and Benedict, Am. Journ. Physiol., 1909, **23**, p. 412.
[2] Chittenden, Pop. Sci. Monthly, 1903, **63**, p. 130; ibid., 1907, **71**, p. 536.
[3] Chittenden, Pop. Sci. Monthly, 1903, **63**, p. 130.

Mr. Fletcher was also studied in 1903 for three successive days inside the respiration calorimeter at Wesleyan University.[1] While his daily activities were necessarily somewhat restricted by the confines of the respiration chamber, a careful record of the movements, hours of sleep, etc., and analyses of both intake and output in terms of chemical elements and of heat showed that the energy transformations of Mr. Fletcher were in no wise different from those of normal individuals. With present-day knowledge of the factors influencing metabolism, we may say, however, that probably Mr. Fletcher's age at that time (54 years) must have played a slight rôle. Here again, therefore, the search for a materially lowered metabolism was unavailing.

Another prominent food investigator studied was Dr. J. H. Kellogg, who has given not a little attention to his own diet, and whose interest and activity in dietetic régimes are well known throughout this country. Subsisting upon a vegetarian diet for many years and particularly on a low protein diet, Dr. Kellogg was convinced that he lived upon a very much lower metabolic plane than the normal individual. This was set forth in a letter published by Mr. Fletcher,[2] from which one infers that Dr. Kellogg believed he subsisted upon approximately 1,200 calories per day. Dr. Kellogg kindly consented to enter the respiration chamber for an experiment comprising several short periods at Wesleyan University in 1906.[3] We were thus able to measure his metabolism when he was asleep, sitting, standing, and walking. From these measurements the probable food requirement was computed. A minimum estimate showed a daily requirement of not less than 2,000 calories. Since the body-weight of Dr. Kellogg was 56.1 kilograms, we thus have a metabolism that is not appreciably lower than that of other individuals, although here again the age factor undoubtedly played some slight rôle.

Another subject who had given special attention to dietetic matters, Dr. M. Hindhede of Copenhagen, was a visitor at the Nutrition Laboratory for a short time in 1910. Although observations could not be made with him according to the strictest basal requirements, nevertheless the metabolism was determined in two or three respiration calorimeter experiments. Although he had presumably been subsisting for several years upon an extraordinarily low-protein and vegetarian diet, his metabolism as measured was not sufficiently low to indicate that his metabolic level was different from that of normal individuals.[4]

The experiment made with Mr. Fletcher at Wesleyan University in 1903 was supplemented by an experiment of only 4 periods at the Nutrition Laboratory in 1912. This was carried out under strictly

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[1] Benedict and Milner, U. S. Dept. Agr., Office Exp. Sta. Bull. 175, 1907, p. 199.
[2] Fletcher, The A. B.-Z. of our own nutrition, New York, 1903, p. xxxiii.
[3] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 126, 1910, pp. 75 and 96.
[4] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918, pp. 191 and 192.

basal conditions, and reported by Benedict, Emmes, Roth, and Smith, in their summary of metabolism measurements for 89 men and 68 women.[1] At this time Mr. Fletcher was 63 years old and appreciably over-weight, having a body-weight without clothing of 82.1 kg., with a height of 166 cm. The measurements of the metabolism gave a heat production of 19.7 calories per kilogram of body-weight per 24 hours. This is materially different from the average of 25.5 calories for the whole group of 89 men and, in fact, is lower than that for any other individual in the group. The nearest approach to this value was found with Professor Otto Cohnheim, who visited the Laboratory at about this time. With an age of 36 years, a body-weight of 83 kg., and a height of 169 cm., Professor Cohnheim (in 12 observations on 3 days) gave a heat production of 19.9 calories per kilogram and per 24 hours. Although Professor Cohnheim was much younger than Mr. Fletcher, of a highly nervous temperament in contrast to the phlegmatic temperament of the latter, and also a liberal meat-eater, the differences in age, temperament, and dietetic habits were more than counterbalanced by the decided overweight of the two men. It is evident that this excess body-weight and adipose tissue had an effect upon the heat production per kilogram of body-weight of both men. Nevertheless the fact remains that the value for Mr. Fletcher of 19.7 calories is the absolute minimum for values obtained with 89 men reported in 1914.

Zuntz and Schirokich[2] report a series of observations made with Mr. Fletcher about three months previous to the experiment at the Nutrition Laboratory, *i. e.*, in February and March, 1912. The Zuntz-Geppert apparatus was used. The investigators conclude that the basal metabolism of this man was on a low plane which was coincidental with a restricted and protein-poor diet, for the subject had been living for 3 months on a diet of potatoes and butter. The post-absorptive values showed a low output of approximately 19 calories per kilogram per 24 hours. As Zuntz and Schirokich point out, this agrees very well with the values found in the respiration calorimeter at Wesleyan University with young men fasting and at rest. The two fasting men studied in the Zuntz laboratory, Cetti and Breithaupt, showed a higher basal metabolism of from 29 calories with Cetti to 24 calories with Breithaupt. While the Fletcher values are complicated by the factors of age and weight, the experiments distinctly suggest a lower metabolism with a low nitrogen intake. Although Zuntz speaks of the diet as being restricted, the caloric intake of 2,750 calories in the first period should certainly be sufficient to cover the needs of the subject. In the second period the caloric intake of 2,116 calories is probably somewhat less than the actual requirements of the body.

[1] Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 139.
[2] Zuntz and Schirokich, Separate from Med. Klinik, 1912, No. 32, 5 pp.

Since the metabolism of Mr. Fletcher has been a matter of unusual interest, the results thus far obtained with him are summarized in table 1, these including the early observations at Wesleyan University in 1903, the observations made by Zuntz and Schirokich in February and March, 1912, and those made at the Nutrition Laboratory in May of the same year.

TABLE 1.—*Basal metabolism of Horace Fletcher (lying).*

Date.	Age.	Body-weight without clothing.	Height.	Body-surface.[1]	Observation.		Heat.		
					Days.	Periods.	Per 24 hours.	Per kilogram per 24 hours.	Per square meter per hour.[1]
	yrs.	*kilos.*	*cm.*	*sq. m.*			*cals.*	*cals.*	*cals.*
Nov. 10–13, 1903[2]	54	71.6	168	1.81	3	3	1610	22.5	37.1
Feb. 16–21, 1912[3]	63	ca. 76.0	166	1.84	3	6	1458	19.2	33.0
Mar. 8–16, 1912[3]	63	76.1	166	1.84	6	12	1471	19.3	33.3
May 7, 1912[4]	63	82.1	166	1.90	1	4	1615	19.7	35.4

[1] Body-surface computed from height-weight chart of Du Bois. Arch. Intern. Med., 1916, **17**, p. 863.

[2] Benedict and Milner, U. S. Dept. Agr., Office Exp. Stas. Bul. 175, 1907, pp. 51, 84, and 199. Values obtained between 1 a. m. and 7 a. m. Strictly speaking, subject not in post-absorptive condition, as a predominatingly carbohydrate supper, containing about 500 calories, was eaten at 7 p. m.

[3] Zuntz and Schirokich, Separate from Med. Klinik, 1912, No. 32, 5 pp. Subject had been living on a continued scanty protein-poor diet (potato and butter).

[4] Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 142.

While unquestionably during the study of Zuntz and Schirokich the subject was living on a scanty protein-poor diet and had been for some time, we have no positive information as to his dietetic habits during May of 1912, when he was studied at the Nutrition Laboratory. From the body-weight in May one would be inclined to think that he had been living upon a rather liberal diet, the weight being 82.1 kg. as compared with 76 kg. in February and March. Nine years before (in 1903), when the body-weight was 71.6 kg., the metabolism as determined at Wesleyan University was distinctly higher. It is clear, therefore, that the evidence presented by Mr. Fletcher may not be taken alone as indication of a reduced metabolism resulting from chronic undernutrition. While there is no doubt that the protein intake during a considerable period of time may have been low, the fluctuations in body-weight indicate somewhat wide variations in the dietetic habits of this subject as to the energy intake.

In the 1903 study, in the selected period between 1 and 7 a. m., when the subject was in bed inside the respiration calorimeter and without food, we find that the heat production per kilogram of body-weight was

22.5 calories with a body-weight of 71.6 kg. Nine years later, in 1912, when he was studied in February and March by Zuntz and Schirokich, and in May at the Nutrition Laboratory, the values obtained per kilogram of body-weight were 19.2, 19.3, and 19.7 calories. His basal metabolism at or about this time was thus a little over 19 calories per kilogram per 24 hours, which is distinctly low. Two factors, however, have an important bearing here. One is obesity, for, with a height of 166 cm. and an age of 63 years, the normal weight would be 65 kg.,[1] while Mr. Fletcher's weight ranged from 76 to 82 kg. The excessive adipose tissue would tend to lower the heat production per kilogram. Secondly, the element of age should be considered, for, as has been shown by practically all the observations thus far available, with advancing years there is a definite tendency to a lowering of the metabolism. While, therefore, Mr. Fletcher's metabolism was distinctly lower than the normal average, it is by no means evident that this was due in any part to dietetic habits or to any other known factor than those of age and obesity.

The nitrogen output has a special interest in this connection when considered as an index of the level of the protein katabolism. The data for the nitrogen output for most of these subjects with presumably low metabolism have been collected in table 2, which shows that Prof. C.

TABLE 2.—*Nitrogen excretion of subjects studied for low metabolism.* (Subjects post-absorptive.)

Subject.	Nitrogen excretion per kilo. per hour.	Date.	Literature references.
	mg.		
Prof. C*	[1]8.3	Nov. 17, 20, 22, 1909.	[1] Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 136, 1910, p. 196.
H. F...	[1]5.6	Nov. 19, 1909.	[2] From unpublished material at Nutrition Laboratory.
H. F...	[2]4.5	May 7, 1912.	[3] Based on per 24 hour determinations; subject not post-absorptive but on a low nitrogen diet. Zuntz and Schirokich, Separate from Med. Klinik, 1912, No. 32, 5 pp.
H. F...	[3]2.5	Feb. and Mar., 1912.	[4] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918, pp. 177, 191, and 192.
Dr. H..	[4]5.0	Feb. 14, 1910.	
Dr. H..	[4]4.6	Feb. 17, 1910.	

* Introduced for comparison.

has a nitrogen excretion per kilogram per hour of 8.3 mg. This is somewhat higher than the average found for 10 subjects, including Prof. C. and H. F., and reported by Benedict and Joslin,[2] the average for all subjects being 6.85 mg. On the other hand, both Dr. H. and H. F. show a low nitrogen excretion, the average of two experiments

[1] Computed from table 4, Medico-Actuarial Mortality Inv., New York, 1912, 1, p. 38, deducting 8 lbs. for clothing.

[2] Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 136, 1910, p. 196.

with Dr. H. being 4.8 mg. and the three values found for H. F. being 5.6, 4.5, and 2.5 mg. No post-absorptive nitrogen figures are available for Dr. Kellogg. It is clear, however, that Prof. C. was excreting nearly twice as much nitrogen as the other subjects and hence was on a fairly high nitrogen level. The fact that his metabolism per kilogram of body-weight was so low—but 0.2 calorie higher than that of H. F. or 19.9 calories as compared with 19.7 calories—must in all probability be due solely to excess body fat. Both subjects were distinctly over-weight and showed low metabolism per kilogram of body-weight.

It thus appears that a critical examination of the metabolism data for these individuals with supposedly low metabolism does not show appreciable deviations from the normal. With a rare pathological case there may be justification for laying weight upon the metabolism of a single individual, but the Nutrition Laboratory has, in recent years, strongly opposed the use of such individual data for comparison. Furthermore we have strenuously objected to an undue use of a so-called "standard" figure for the metabolism, as we believe that individual variations may be so great as to render these individual comparisons practically valueless. Hence, while the evidence for both Mr. Fletcher and Dr. Kellogg, and particularly the latter, did not indicate a noticeably low metabolism due to dietetic habits, it seemed best to study the question with groups of individuals, since with these only can convincing data be obtained.

With the idea that a vegetarian diet, which might be assumed to be likewise a low-protein diet, would result in a low metabolism, a series of investigations was carried out with approved technique at the Battle Creek Sanitarium, by Benedict and Roth (Journ. Biol. Chem., 1915, *20*, p. 231). Through the courtesy of Dr. Kellogg, a large number of men and women vegetarians were thus studied. It became clear to us at this time that the so-called group system of comparison was absolutely necessary, namely, that only individuals of like height and weight may properly be compared. Hence for comparison with the men and women vegetarians we selected a group of normals, *i. e.*, non-vegetarians, of like weight and height. The vegetarians, even with a presumably low nitrogen output and a less stimulated plane of metabolism due to the lowered nitrogen metabolism, did not have a lower total metabolism than the individuals subsisting on a mixed diet.

In an analysis of the results obtained with some 150 individuals[1] it was found not only that, strictly speaking, there is no constancy in the basal metabolism, but also that those instances in which the metabolism is low give no indication of a general picture of unusually low metabolism due to other than well-known causes. In consideration of the fact that sex, age, muscular training, and body composition (*i. e.*, proportion of inert body-fat and active protoplasmic tissue), height in

[1] Benedict, Journ. Biol. Chem., 1915, **20**, p. 263.

individuals of the same weight and age, sleep, and the after effect of exercise, all have an influence upon the basal metabolism, the conclusion was drawn that the basal metabolism of an individual is a function, first, of the total mass of active protoplasmic tissue and, second, of the stimulus to cellular activity existing at the time the measurement of the metabolism was made. It was furthermore maintained that "apparently at present no law can be laid down that will cover both of these important variables in the basal metabolism of an individual."[1]

STUDY OF FACTORS TENDING TO LOWER METABOLISM.

In our study of variations in basal metabolism, special consideration has been given to the question of those factors which tend to lower the metabolism, and it was early recognized that prolonged fasting produced such an effect. The results obtained at the Nutrition Laboratory during the 31-day fasting experiment[2] on the subject L. are decisive on this point. Here the analysis was first made upon the basis of per kilogram of body-weight and per square meter of body-surface; the body-surface was computed by the old formula of Meeh. By both methods of computation, definite loss in heat production was found as the fast progressed, save that after the fourteenth or fifteenth day there was a tendency to constancy. A subsequent revision of the calculations of body-surface, based upon a series of photographs and the more modern Du Bois measurements,[3] confirmed the earlier findings and placed them upon a more scientific basis.

A somewhat complex factor entered into the interpretation of the values for the basal metabolism of this fasting man in that a definite acidosis developed. Although we believe that acidosis tends to stimulate the metabolism and thus would partly offset the depressing effect of the fasting *per se*, nevertheless there is no question but that the metabolism per kilogram of body-weight or per square meter of body-surface was distinctly lowered as a result of fasting. Of particular significance is the fact that with this fasting man there was no proportionate loss of strength but a general feeling of unimpaired mental and physical activity. While the subject showed a falling off in the dynamometric tests, from a superficial observation one would never realize that the man had been without food for 31 days. In talking to a group of medical men on the thirty-first day of his fast, he exhibited all the vivacity, strength of voice, and vigor of gesture that an ordinary individual would use. We thus have here evidence of a depressed metabolism unaccompanied by marked loss in intellectual or physical powers. It was demonstrated, therefore, that a specific factor, namely, complete inanition, can produce a definite and thoroughly established lowering of metabolism.

[1] Benedict, Journ. Biol. Chem., 1915, **20**, p. 299.
[2] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915.
[3] Benedict, Am. Journ. Physiol., 1916, **41**, p. 292.

The next evidence obtained in the Nutrition Laboratory of a pronounced decrease in the metabolism was the metabolic condition subsequent to the Allen fasting treatment for diabetes. In an extensive series of observations on metabolism in diabetes made in this Laboratory in conjunction with Dr. Elliott P. Joslin, cases of severe diabetes of the acid type showed high metabolism when compared with groups of normal individuals of like height and weight. After a few days' fasting under the remarkable Allen fasting treatment, the acidosis disappeared and the previously existing high metabolism was followed by a striking decrease in metabolism to far below that of the controls. This fall in the metabolism was found in so many cases that it may be considered as thoroughly established. It was subsequently verified by Du Bois in direct calorimetric observations. It may naturally be inferred that the cases of severe diabetes represent extreme emaciation or inanition, and hence it is appropriate to compare them with the man who fasted 31 days. From the diet charts of these patients after the Allen fasting treatment we find surprisingly low food-intakes. Yet these individuals are not moribund; they are able to be about the hospital, perform their own urinary tests, attend conferences, and engage in exercise even to the extent of walking 3 or 4 miles per day. While not rugged, they are by no means confined to bed, and yet they show this extraordinarily low basal metabolism. It appears, therefore, that with great loss of flesh there is a distinctly lower basal metabolism. We accordingly have here a second clear index of a lower metabolic level.

As a result of this long study of variations in basal metabolism and the factors which depress metabolism, we thus found a lower basal level only during fasting and with diabetics subsequent to the Allen fasting treatment. Since our earlier researches produced such negative results, it is incumbent upon us to examine previous studies interpreted as signifying a depressed metabolism due to undernutrition or other conditions and to present a critique of the results obtained.

PREVIOUS INVESTIGATIONS ON METABOLISM WITH UNDERNUTRITION.

Many of the researches on undernutrition in the earlier literature were made with animals, and some were carried out under pathological conditions. In collecting data regarding the previous investigations on undernutrition, the studies dealing solely with the loss of nitrogen have been purposely omitted, for only in rare instances have there been satisfactory determinations of the balance of nitrogen intake and output for indicating a true gain or loss to the body. The total nitrogen outgo, *i. e.*, the nitrogen in the urine and feces, may be accurately determined without extraordinary analytical procedure, but this tells only half the story and must be supplemented by data regarding the intake. The difficulty of sampling and analyzing mixed diets to secure the total nitrogen of intake is obvious; computed values have, at best, but little significance. Moreover, the nitrogen data are in many of the studies complicated by distinct pathological conditions, thus excluding them from special consideration in a study of the influence of undernutrition on normal healthy people. It seems best, therefore, to disregard the literature bearing upon the subject of the loss of nitrogen due to undernutrition and to confine the discussion of the previous findings solely to the influence of undernutrition upon the gaseous metabolism.

Pettenkofer and Voit, 1871.—The importance of studying animals in different stages of nutrition was early recognized by Pettenkofer and Voit,[1] who made observations in which 500 to 2,500 grams of meat were fed daily to a dog weighing approximately 35 kg. The smaller portion of food, which corresponds more specifically to undernutrition, was continued for approximately 6 weeks. At first sight it appears as if an experiment of this type would throw definite light upon the demands of the body while on a low nutritional plane. The experimental technique, however, which unfortunately was followed by a number of later observers, involved feeding the animal with meat, placing it at once inside the respiration chamber, and then making observations on the respiratory products in 24-hour periods. It is to be regretted that the excellent method frequently employed by Pettenkofer and Voit of separating their experimental period into day and night periods was not here used, for it is undoubtedly true that during the first hours of the day the metabolism was greatly stimulated by the ingestion of meat, the stimulation being approximately proportional to the amounts of meat ingested. The metabolism as measured, therefore, was not basal metabolism, but basal metabolism plus the stimulus of meat. The authors note that there was a distinct falling off in the metabolism when the smaller quantities of meat were given, 500 grams of meat

[1] Pettenkofer and Voit, Zeitschr. f. Biol., 1871, 7, p. 433.

representing scarcely half the dog's requirements. While Pettenkofer and Voit have not specifically discussed in detail the undernutritional stage of this series of experiments, their data are referred to and in a certain sense recalculated by Rubner.[1] In discussing these and some other experiments Rubner recognizes that, in addition to the loss in body substance produced by acute or prolonged hunger, the heat-production usually decreases in proportion to the decrease in mass, but points out the possibility of individuality. In Pettenkofer and Voit's experiments, while there was no measurable loss in carbon-dioxide excretion per kilogram of body-weight during the period of undernutrition, in which the body-weight varied from 34.4 to 30.0 kg., there was a much greater heat-production, as measured by the carbon-dioxide output, with a diet of 1,500 grams of meat than with 1,000 grams. The fact that the actual basal metabolism was not measured makes it difficult to interpret these experiments as evidence of a decrease in the basal metabolism due to undernutrition.

Klemperer, 1889.—Although based primarily upon nitrogen measurements and body-weight rather than upon the metabolism, Klemperer's[2] conception of the adjustment of the body to high or low diets is the first clearly formulated. In his celebrated experiment on a tailoress, Klemperer, arguing from the fact that body nitrogen was in equilibrium and that consequently the calories must have been in equilibrium, maintained that this individual could, when resting in bed, subsist upon 18 calories per kilogram per 24 hours. Both experiment and conclusion have been adversely criticized by von Noorden,[3] but Klemperer was the first to indicate "die Möglichkeit und Wahrscheinlichkeit verringerten Energieumsatzes" or "die Lehre von der Anpassung des Umsatzes an die gereichte Kost."[4]

Lehmann, Mueller, Munk, Senator, and Zuntz, 1893.—The classic experiments made by Lehmann, Mueller, Munk, Senator, and Zuntz[5] on two fasting men must be interpreted in the light of the present day knowledge of the influence of fasting upon metabolism. Zuntz and Lehmann concluded, because the heat production of the subject Breithaupt after the fast was less, even with a larger diet, than before the fast (24.8 as compared with 27.3 calories per kilogram per 24 hours), that with certain conditions the undernourished body may use foodstuffs more economically than a well-nourished body, but emphasize the fact that further information is desirable. We now know that fasting *per se* depresses the metabolism. The ingestion of food first offsets this depression, then stimulates the metabolism to higher

[1] Rubner, Gesetze des Energieverbrauchs bei der Ernährung, Leipsic, 1902, pp. 296–297.
[2] Klemperer, Zeitschr. f. klin. Med., 1889, **16**, p. 597.
[3] von Noorden, Metabolism and practical medicine, 2, Pathology, Chicago, 1907, foot-note 1, p. 5.
[4] Magnus-Levy, Zeitschr. f. klin. Med., 1906, **60**, p. 203.
[5] Lehmann, Mueller, Munk, Senator, and Zuntz, Arch. f. path. Anat. u. Physiol., 1893, **131**, Supphft., p. 1.

activity; hence these experiments are not clear evidence on undernutrition and serve only to point out the error of using the last day of fasting for a base-line.

Russian research on undernutrition: V. V. Pashutin, Albitsky, and I. A. Pashutin, 1887–1902.—While prolonged fasting and complete starvation have received experimental attention in a great many physiological laboratories, surprisingly little attention has been paid to chronic undernutrition, except in Russia. Russians fast frequently during the year and chronic undernutrition is common among the poor classes. It is probable, however, that in the religious fasting seasons the Russians do not fast in the strictest sense of the word, as they are said to continue their work with apparent vigor and sustained vitality, although they lose in weight, indicating that the nutrition must be insufficient.[1] As a result of the frequent occurrence of incomplete nutrition among the Russian people, we find that the metabolism during undernutrition was studied in the laboratory of Professor V. V. Pashutin by Albitsky and later by I. A. Pashutin. In these well-planned investigations studies were made of the metabolism of animals during insufficient feeding and subsequent realimentation.

The series of experiments made by Albitsky was extensively discussed by the senior Pashutin in his course on general and experimental pathology.[2] The experiments made by the younger Pashutin are reported in a dissertation published in 1895, which gives one of the best general discussions of undernutrition printed as early as that date.[3] In this dissertation Pashutin raises the question as to whether the vital processes would be affected if the normal diet were reduced one-fourth, one-third, or one-half.

The primary object of Albitsky's experiments was to study the influence of repeated periods of complete fasting (with or without water) and subsequent realimentation. One of the tables in Pashutin's book shows the carbon-dioxide excretion and oxygen consumption for Albitsky's rabbit No. 4, in four successive fasts, and the first and third realimentation periods. For comparison, the table also gives an average normal value which was determined during 4 days of normal feeding prior to the third fasting period. Unfortunately no normal value for the gaseous exchange, either in the post-absorptive state or with food, was obtained before the beginning of the first fasting period. During the first few days of the first and third realimentation periods, the rabbit, confined in the Pashutin respiration chamber, received food for only a few hours daily. Since it is the custom of these animals to eat

[1] I. A. Pashutin, The metabolism of animals during insufficient feeding and subsequent realimentation. Diss., St. Petersburg, 1895. See introduction.

[2] V. V. Pashutin, General and experimental pathology (Pathological Physiology), St. Petersburg, 1902, 2 (1), p. 177 (Russian). So far as we know, the full details of these experiments are given in no other place, although mention is made of the fact that the experiments were published in part in the report of a convention in Moscow in 1887.

[3] I. A. Pashutin, loc. cit.

intermittently the greater part of the 24 hours, the rabbit received an insufficient amount of food on these first days, the intake being roughly proportional to the length of time in which the rabbit had access to food. The values obtained during these realimentation periods supply the only data which have an interest in our discussion of the influence of undernutrition.

In the first 3 days of the first realimentation period, the solid matter eaten was but 13, 34, and 36 per cent, respectively, of the amount eaten during the normal period; on the corresponding days in the third realimentation period, it was 62, 49, and 33 per cent, respectively. Since the intake of solid material did not reach the normal amount until the seventh day in the first realimentation period and the sixth day in the third realimentation period, the animal was distinctly undernourished in the earlier days of these periods. On the first day of the first realimentation period, the oxygen consumption per kilogram of body-weight per 24 hours was a little more than one-half the normal value (15.81 grams as compared with 27.58 grams). In the third realimentation period, the oxygen consumption for the first day was 25.08 grams. The carbon-dioxide excretion on the first days of these realimentation periods was 17.79 and 32.16 grams, respectively, and thus much lower than the normal value of 42.41 grams. The oxygen consumption and carbon-dioxide excretion, particularly in the third period, did not return to normal until the food intake was essentially that prior to fasting. During these two periods of undernutrition, therefore, the metabolism per kilogram of body-weight was considerably lower than normal, the oxygen being from 43 to 9 per cent less and the carbon dioxide from 58 to 15 per cent less in the first and third realimentation periods, respectively. While the difference in the carbon-dioxide excretion may naturally be accounted for, in part, by the difference in character of the carbonaceous material in the food, the values would indicate that during chronic undernutrition there is at first a distinct lowering of the metabolism per kilogram of body-weight when measured by either the oxygen consumption or the carbon-dioxide excretion, as compared with the metabolism with a normal amount of food. The fact, however, that the oxygen consumption increases from 43 to only 9 per cent below normal in the third realimentation period would indicate that with the larger diet in the third period the metabolism immediately tended to follow the higher plane of nutrition.

This finding is substantiated by a comparison of the metabolism during the realimentation periods with the metabolism on the first days of the first fasting period, for, aside from the expected increase in metabolism due to the influence of the ingestion of food, Albitsky reports that the intensity of metabolism, even with an insufficient amount of food, was greater in the later realimentation period as compared with the earlier. Albitsky's whole conception, however, is com-

plicated by the fact that considerably larger quantities of food were taken during the third realimentation period. It is interesting to note in this connection that the statement is made that on account of this greater intensity of metabolism which was accompanied, at least in some experiments, by a high temperature,[1] the animal in the realimentation period should eat from 1 to 1.5 times as much food as would be taken normally and drink twice as much water to regain the weight lost in fasting.

While it should be borne in mind that Albitsky's observations on realimentation and metabolism during undernutrition were incidental to the major study, continuing only 3 or 4 days, and the deductions are thus based upon fragmentary evidence, his final conclusions are that, during realimentation with a diet below maintenance, the metabolism per kilogram of body-weight was at first distinctly lower than normal, but as the undernutrition continued, the metabolism gained in intensity till it more nearly approached the normal. These conclusions are distinctly open to question on account of changes in the amount of food administered during the compared periods.

In contradistinction to Albitsky's conclusions, a statement is made in the dissertation of the younger Pashutin[2] that a full-grown rabbit, well fed and in a condition of equilibrium, when gradually deprived of 25 to 50 per cent of its food and the low nutrition continued for some time, showed but little change in the vital processes and general health, so far as could be judged by the body-weight. This paradoxical phenomenon of the actual change in the metabolism of animals under such conditions of reduced diet was confirmed by the younger Pashutin's later study in the same laboratory. An apparatus on the closed-circuit principle, devised by Professor V. V. Pashutin, was used for measuring the carbon-dioxide excretion and the oxygen consumption.

In this study, rabbits and subsequently dogs were employed. The plan was ingenious in that the amount of nutriment required for maintenance was first determined and then a certain percentage of the food was gradually withdrawn. The attempt was made in the undernutrition period so to adjust the diet that the loss in body-weight should be less than 15 per cent. This was done on the supposition that degenerative changes in the organs and tissues would appear with a 15 per cent loss in weight or, according to one Russian observer, Okhotin, with a 10 per cent loss. Although the food of the first rabbit was reduced to 85 per cent of the normal requirement, the total carbon-dioxide excretion and oxygen consumption did not change or at least did not exceed normal fluctuations. Since the body-weight of this particular rabbit fell only 6 per cent, it is probable that no definite conclusions can be drawn from the data. With a second rabbit the

[1] Another Russian writer, Manassein (Medical Information, 1871), in experiments with animals with complete starvation, also noted a high temperature, which he characterized as febrile.

[2] I. A. Pashutin, loc. cit.

food was reduced to 67 per cent of the normal needs and the body-weight fell 11 per cent. As a result of these experiments with rabbits, it appeared perfectly possible to reduce the diet considerably with almost inappreciable alteration in the total oxygen consumption. Since the curtailment in diet produced only slow changes in the body-weight and since, in the absence of evidence as to the activity of the animal under observation, it must be assumed that the activity was relatively constant, it follows that the lowered food intake was without appreciable effect upon the metabolism.

In experiments with dogs, Pashutin found that when the diet was reduced to 75 per cent of the normal requirement, neither the oxygen consumption nor carbon-dioxide production was appreciably altered. On the other hand, the period of observation was so short (apparently not far from 2 weeks) that the diet was not sufficiently low to alter materially the body-weight.

A dog, with which observations were begun January 15, was fed for a month with 500 grams of horse flesh daily. Its weight in the middle of February was 6,098 grams. The food was then reduced and 75 per cent of the normal diet given for 19 days, 65 per cent for 29 days, and 55 per cent for 7 days. During the last period the animal fell to a weight 10.6 per cent below the initial weight. He was subsequently fed with 500 grams of meat for 24 days; a second undernutrition period of 33 days with 55 per cent of food followed. Under these conditions it was found that when 75 per cent of food was given, the oxygen consumption and carbon-dioxide excretion fell to about 88 per cent of the normal; it was not until the food was reduced to 55 per cent of the normal diet that the gaseous metabolism fell to approximately 75 per cent. In the realimentation period the gaseous metabolism did not return to the normal amount. In the second undernutrition period the oxygen fell to 71 per cent and the carbon dioxide to 66 per cent of the normal excretion. During the second realimentation period of 23 days with 500 grams of meat the animal gained in weight so that he was 26 per cent above normal. Even under these conditions the oxygen consumption was only 79 per cent of normal and the carbon-dioxide production 74 per cent. With this dog, therefore, it is clear that the reduction in diet was accompanied by a distinct fall in the respiratory exchange, a fall that was not compensated by realimentation, even when the body-weight increased to 26 per cent above normal.

A second dog was brought into equilibrium at a body-weight of 6,221 grams by feeding with an abundance (617 grams) of horse flesh. The food was then reduced to 63.2 per cent of his normal amount. This period of undernutrition continued 23 days. The dog was next fed for 28 days with approximately 3 per cent above the normal amount of food. A second undernutrition period of 22 days followed, in which the food

was again reduced to 63.2 per cent. As during the realimentation period the animal had gained in weight to more than 20 per cent and even during the second period of lowered food intake it was 17 per cent above weight,[1] the investigator further gradually reduced the food to bring the body-weight to the original point. To do this it was finally necessary to reduce the food to approximately one-third of the normal amount and continue this diet for four weeks. The author concludes from these experiments that the sudden curtailment of food had a much greater effect upon the metabolism than a gradual reduction of food intake. At no period of the realimentation process did the gaseous metabolism exceed normal; in fact, when the food intake was two-thirds that of the normal amount, both the oxygen consumption and carbon-dioxide production approximated 75 to 80 per cent of the normal. During the period of very greatly reduced intake, when the food finally reached but 30 per cent of the maintenance amount, no gaseous metabolism measurements were made.

With a third dog the food was reduced to 50 per cent of normal, the reduction being made at the rate of 1 per cent of the food quantity per day. After the reduction reached 80, 70, 60, and 50 per cent, a 3-day study of the gaseous metabolism was made at each of these points. The whole experiment lasted 87 days. The body-weight at the end of the low feeding was 13 per cent below the initial weight; the gaseous metabolism per kilogram decreased with oxygen to 94.6 per cent and with carbon dioxide to 86 per cent of the initial quantities.

Pashutin points out, with a conservatism which could well be followed by many modern writers, that his conclusions are based upon only two complete experiments in which the metabolism during realimentation was studied, and therefore he ascribes no great value to them. They are, however, at variance with those of Albitsky, who noted an increment in oxidation[2] during the realimentation periods following starvation, while in Pashutin's experiments the chronic undernutrition resulted in a distinct lowering of metabolism per kilogram of body-weight. Even when the maintenance diet was exceeded, the gaseous metabolism did not reach normal, thus indicating a distinct lowering in the plane of metabolic activity.

Svenson, 1901.—Svenson,[3] interpreting many observations in the earlier literature as indicating lowered energy requirements with chronic undernutrition, attacked the problem from the standpoint of changes in metabolism during convalescence from typhoid fever or pneumonia. He sought to discover if, during convalescence, there was an attempt made by the organism to economize by reducing oxidation, as he considers is done in chronic undernutrition. Employing the

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[1] These conditions seem inexplicable except on the ground that the initial equilibrium weight of 6,221 grams was in reality overweight, and accompanied by excess food intake.

[2] This, we believe, is due in large part to the larger food intake (see page 16).

[3] Svenson, Zeitschr. f. klin. Med., 1901, **43**, p. 86.

Zuntz-Geppert apparatus, Svenson found that with typhoid patients in the first period of convalescence and in the *nüchtern* condition, there were for a short time subnormal values for carbon-dioxide production and oxygen consumption, but the values soon increased until they gradually became abnormally high and subsequently fell again to normal values. He concludes that the lowering of the oxidation processes in the first stages of convalescence is not a sign of a definite adjustment of the organism to a lower level, but rather is incidental to the exhaustion of the organism. After long illness the functions of all the organs suffer more or less and the sensitivity of the nervous system is decidedly lowered; but when the subject's organism and the central nervous system have recovered to some degree, exhaustion disappears and gives place to an increase in metabolism. On the whole, his evidence can be interpreted as indicating low metabolism with chronic undernutrition and high metabolism with excess food.

F. Müller, 1903.—Friedrich Müller[1] admits that with long-continued undernutrition due to disease or lack of food, a lower body-weight can be maintained with a much smaller intake of food and lower oxidation processes, but nevertheless considers that such decrease of oxidation is small and the cases are exceptional.

Richter, 1904.—The small amount of evidence regarding gaseous metabolism obtained in the study of Richter[2] on a patient with esophagus stricture does not lead to clear deductions as to metabolism during excess feeding following emaciation. Although there was a large increase in body-weight and storage of nitrogen, the average values for the respiratory exchange of 4.8 c.c. of oxygen and 3.76 c.c. of carbon dioxide per kilogram per minute, while representing perhaps the higher border of normal values, cannot of themselves be taken as clearly indicating an excess metabolism. The gaseous metabolism measured 3 hours after the ingestion of food showed a normal stimulation from food.

Magnus-Levy, 1906.—In his study of the influence of disease on metabolism, Magnus-Levy[3] cites a striking illustration of chronic undernutrition and gives a lengthy series of respiration experiments with this subject at different stages of body-weight. The height was 160 cm. In the first period, when the body-weight was 36.2 kg., the temperature was subnormal, and the oxygen consumption per kilogram per minute was 3.33 c.c. When the body-weight had risen to 38 kg. the oxygen consumption had risen to 4.1 c.c. At 52.2 kg., when the subject was essentially under normal conditions of nutrition, the oxygen consumption was 4.11 c.c. In discussing this most interesting case, Magnus-Levy refers to Klemperer's research in 1889[4] as the first instance in

[1] F. Müller, v. Leyden's Handb. d. Ernährungstherapie, Leipsic, 1903, 1st ed., **1**, pp. 195 and 196.
[2] Richter, Berl. klin. Wochenschr., 1904, p. 1271.
[3] Magnus-Levy, Zeitschr. f. klin. Med., 1906, **60**, p. 177.
[4] Klemperer, Zeitschr. f. klin. Med., 1889, **16**, p. 550.

which an adjustment of the metabolism to needs was noted. He points out that this is really the expression of a popular conception of the laity, which is also held by many physicians, *i. e.*, that when the food is diminished there is diminished oxygen consumption, and with excess food there is excess oxygen consumption.

Magnus-Levy finds it impossible to explain the lowered metabolism of his subject on the basis of the body-surface law. We must dissent with him, however, when he states (in italics) that a lowering of the body-weight from 55 to 36 kg. produces an insignificant alteration of the body-surface. According to the height-weight chart of Du Bois, a subject having a height of 160 cm. has a body-surface of 1.31 square meters with a body-weight of 36 kg., but with a body-weight of 55 kg. the body-surface is increased to 1.56 square meters, a difference of approximately 20 per cent. Magnus-Levy is further convinced that in this case there was certainly an adjustment of the metabolism to the food consumption, pointing out that this adjustment continued at the low level only so long as the food intake was very low, and that with the large diet the metabolism immediately tended to follow the higher plane of nutrition. This is one of the clearest cases on record of the adjustment of metabolism to needs. It is somewhat surprising that so little attention has been paid to it in current literature.

von Noorden, 1906.—von Noorden's[1] very interesting and suggestive discussion of underfeeding collects the literature on the subject up to the time of publication and shows the singularly deficient evidence with regard to total metabolism as measured by the respiratory exchange under conditions of chronic undernutrition. As von Noorden points out, the experiments on complete withdrawal of food are relatively numerous. These have been supplemented by observations from the Nutrition Laboratory and thus metabolism under complete fasting is fairly well pictured. To what extent the evidence obtained during complete fasting may apply to chronic undernutrition must be considered carefully in this discussion. von Noorden very properly distinguishes between complete starvation and partial undernutrition, but the heat measurements or measurements of the gaseous exchange have rarely been made on conditions other than complete starvation. He points out that Rubner's experiments[2] show that there is a diminishing heat production per kilogram with a progressive loss in weight, but contends that:

"Es muss einstweilen dahingestellt bleiben, ob die bei fortschreitender Abmagerung gelegentlich eintretende Verringerung des Energieumsatzes (pro Kilo) von einer geringeren Lebhaftigkeit der Bewegungen, die mit der Schwächung des Körpers einsetzt, zusammenhängt (Rubner), oder ob das

[1] von Noorden, Handbuch der Pathologie des Stoffwechsels, Berlin, 1906, 2 Aufl., **1**; Metabolism and practical medicine, **2**, Pathology, pp. 1–61, Chicago, 1907.

[2] Rubner, Die Gesetze des Energieverbrauchs bei der Ernährung, Leipsic, 1902, p. 296.

zersetzende Protoplasma, sich der bedrängten Lage anpassend, sparsamer arbeitet."[1]

Falta, Grote, and Staehelin, 1907.—Although the main object of the investigation of Falta, Grote, and Staehelin[2] was to study the specific dynamic effect of individual proteins and the physiological utilization of hydrolyzed protein, certain of their experiments and conclusions have a bearing upon the question of undernutrition. In one series various amounts of meat were fed to a dog weighing approximately 24 kg. The ingenious Jaquet respiration apparatus was employed, but with unfortunately small differences in carbon-dioxide increment and oxygen deficit in the expired air; the errors of gas analysis were therefore greatly magnified. Furthermore, for our purpose of studying the influence of undernutrition, the results are more or less contaminated by the inclusion of the increased metabolism due to the stimulating effect of the meat. Although the experiments are so subdivided as to give measurements in the latter part of the 24 hours, it is questionable whether, when meat was given in large amounts, the entire influence of the food had disappeared even at the end of 24 hours. Several series of experiments were made, each consisting of 3 days. On the first day there was a basal experiment when only water was given. On the second day varying amounts of horse flesh were fed; on the third day there was a second basal experiment. Three such series of experiments were made. Falta, Grote, and Staehelin argue that since during each week the dog was fasting 3 days and fed 4 days he was more or less in a condition of chronic undernutrition.

The authors compare the fasting value on the first day of the first series of experiments with the fasting value on the third day of the third series of experiments, and note that there is a distinct decrease in the heat production per square meter of body-surface per 24 hours amounting to 8 per cent, *i. e.*, from 918.3 to 844.5 calories. They cite this decrease as evidence of the accommodation of the body to the smaller food intake, and point out that this assumption has heretofore lacked definite proof. In explaining some of the differences found in the results obtained with the various proteins—differences that were, to be sure, very small—they argue that it is possible, inasmuch as there is a reduction in the total heat production in the fasting experiments during a condition of chronic undernutrition, that there may likewise be a lessening in the intensity of the specific dynamic action under conditions of chronic undernutrition.

Two criticisms must be raised against the method of computation used by Falta, Grote, and Staehelin. In the first place they have evidently made an error in computing the body-surface of their dog at the end of the third day of the third period. The initial weight was 23.8

[1] von Noorden, Handbuch der Pathologie des Stoffwechsels, Berlin, 1906, 2 Aufl., **1**, p. 486.
[2] Falta, Grote, and Staehelin, Beitr. z. chem. Physiol. u. Path., 1907, **9**, p. 333.

kg. and the final weight 22.8 kg., while they report the corresponding body-surfaces as 0.997 and 0.9916 square meters, respectively. Making corrections for this error in the body-surface, the difference in the heat production per square meter of body-surface is slightly under 7 per cent. With such a subtle factor as the influence of undernutrition upon metabolism, it is highly important that only periods of complete muscular repose be compared. Unfortunately the authors had no record of the degree of repose and in their comparisons include the activity for the whole day. The apparent minimum value for the first day of the first experiment is obtained from two periods with an average oxygen consumption of 11.15 grams per hour. That this is probably an approximate minimum value is shown by the fact that the lowest hourly values for carbon-dioxide excretion are likewise found during these periods. The respiratory quotients for the two periods average 0.72. On the third day of the third experiment we have two periods that also give low minimum values, and these again are in a sense controlled by the fact that the lowest carbon-dioxide excretion per hour appears in the same periods. For the oxygen consumption the values are 10.28 and 10.23 grams, with an average of 10.25 grams per hour; the average respiratory quotient is 0.73.

Calculating the calories per hour on the basis of the calorific value of oxygen for these days and using the average respiratory quotients for the minimum periods, we find that on the first day of the first experiment the values are 36.7 calories per hour, 1.54 calories per kilogram per hour, and 37.3 calories per square meter per hour. For the minimum periods on the third day of the third experiment the values are 33.8 calories per hour, 1.48 calories per kilogram per hour, and 35.3 calories per square meter per hour. The nitrogen excretion in the two days was for the first day 0.216 gram per hour during the period of minimum metabolism, and on the last day 0.20 gram. As these are essentially constant values, we may disregard them in our computation of the total metabolism.

From these figures it is seen that on the two days the metabolism, both per unit of body-weight and per unit of body-surface, was essentially constant, *i. e.*, a difference of but 4 to 5 per cent. Thus the entire argument of Falta, Grote, and Staehelin falls to the ground when based on these experiments, as the results can not be used for positive proof of the assumption that with long-continued undernutrition there is an adjustment of the body to the lower food intake.

Staehelin, 1909.—In an interesting address dealing specifically with the problem of the lowering of metabolism, Staehelin[1] cites many of the cases in literature in which normal individuals showed a lowered metabolism and definitely emphasizes the fact that there may be an adjustment of the metabolism to the nourishment.

[1] Staehelin, Deutsch. med. Wochenschr., 1909, **35**, p. 609.

Hunt, 1910. The effect of a restricted diet upon the resistance of animals to certain poisons was studied by Hunt[1] in an extensive series of experiments on mice and guinea-pigs. The author assumes that acetonitrile exerts its toxic effects only, or largely, after undergoing changes due to the processes of metabolism, the intensity of the processes of oxidation determining the intensity of the toxic effect. The diet given the experimental animals, while qualitatively the same, was less than that of the animals on the unrestricted diet. The dose of acetonitrile dissolved in water was injected subcutaneously; the amount used was proportional to the body-weight. Only those experiments in which the dose was nearly fatal are cited. It was ascertained as typical of these experiments, that with equal doses of acetonitrile the animal on an unrestricted diet died, while that on the restricted diet recovered. This was interpreted as showing a diminution in the intensity of the processes of metabolism with restricted diet.

Grafe, 1910.—In his first publication on metabolism during katatonia, Grafe[2] points out that in spite of what he considers sufficient food, namely, 1,400 calories per day, the body-weight remained constant at 47.5 kg. as compared with an initial weight of approximately 55 kg. He concludes that the body does not exhibit a tendency to increase in weight, and considers this as possibly a peculiarity of katatonia. We have here one of the earliest suggestions in Grafe's writings of the conception of an adjustment of metabolism to food intake, viz., that with increased food intake there is increased energy expenditure.

Grafe, 1911.—In a special search for pathological conditions in which a retardation of basal metabolism would be noted, Grafe,[3] in a carefully planned series of experiments, studied the metabolism of patients in psychiatric coma. Obtaining his subjects from the Psychiatric Institute in Heidelberg, he placed them in the Jaquet respiration chamber in the Clinic for experiments lasting from 3 to 12 hours or more. If we consider only those experiments in which the subjects remained very quiet, we find in certain cases of mental disturbance accompanied by stupor that the basal metabolism, either per kilogram of body-weight or per square meter of body-surface (using the Meeh formula), is extraordinarily low. In one case it was 39 per cent below the value selected by Grafe as a normal, namely, 800 calories per square meter per 24 hours.

Grafe finds it difficult to explain this depression in metabolism as being caused by chronic undernutrition. Grafe's patients, although admittedly somewhat undernourished when compared with the average of normal people of the same age, were far from being ema-

[1] Hunt, Public Health and Marine-Hospital Service of the U. S., Hygienic Laboratory Bull. No. 69, 1910.

[2] Grafe, Zeitschr. f. physiol. Chem., 1910, **65**, p. 45.

[3] Grafe, Deutsch. Arch. f. klin. Med., 1911, **102**, p. 15.

ciated. It so happens that the most pronounced depression in metabolism occurred with a woman with a height of 162 cm. and a weight of 71 kg., who was in an unusually good state of nutrition. Recognizing the difficulties of interpreting this phenomenon, Grafe cautiously states that the experiments simply establish the fact that with mental disease there is a true depression in the metabolism. His experiments on subsequent feeding are somewhat less numerous and indicate that while the maximum effect following food may not appear so soon as with normal people, the total increase in oxidation as the result of food ingestion is essentially normal.

It is quite clear, therefore, from this study of Grafe's, that the basal metabolism during conditions of mental disturbance accompanied by stupor may be very considerably lowered. The lowered values are so great that they can not be ascribed to errors in the selection of a normal value or to a possible error in the body-surface values as compared with the more recent body-surface standards of Du Bois. As an indication of the possibility of alteration in basal metabolism the investigation has a profound interest. Since the majority of Grafe's patients were not unduly emaciated, it is quite likely that we deal here with a specific result of the mental condition accompanied by stupor and not to a distinctly undernourished condition of the body with lessened cell-mass.

Grafe and Graham, 1911.—The lengthy observation of Grafe and Graham[1] on excess feeding of a 20-kilogram dog has provoked an unusual amount of discussion among physiologists, in spite of the fact that relatively little adverse criticism has been printed. Although primarily considering the question of overfeeding, the experiments have such a bearing on the possible adjustment of basal metabolism to food intake and have received so much attention from physiologists that we feel justified in discussing them here. Personal acquaintance with Dr. Grafe has led to a thorough investigation of this remarkable research, and it is a source of much regret that the present war conditions do not make it possible, before publication, to communicate with Dr. Grafe regarding our critical examination of his study. Although we are forced to dissent from the main conclusions, we are fully aware of the important place that the research has taken in physiological circles and the stimulus it has been to thought and to research.

The dog was first starved for 21 days. It was then given presumably excess food (280 per cent of the basal requirement) until the normal weight was regained (a period of 7 days). This was followed by 29 days of gross excess feeding (300 per cent of the basal needs), and three subsequent periods of 11, 19, and 10 days, respectively, with a smaller amount of food, but still presumably above the normal requirement (200, 130, and *ca.* 100 per cent). During the last three periods the dog remained with an essentially constant body-weight. Grafe argues that

[1] Grafe and Graham, Zeitschr. f. physiol. Chem., 1911, 73, p. 1.

this indicates an adjustment of the body to the excess nourishment. While the main argument is based upon the fact that the body-weight did not change, Grafe presents in addition a number of respiration experiments made during the period of supposed excess feeding, which he compares to a basal value and thus satisfies himself that during the period of excessive feeding there was a very greatly increased *nüchtern* metabolism.

At first sight the experiment seems to be carried out with unusual care and accuracy; furthermore, Grafe gives a very good exposition of the main points under discussion. Unfortunately we find it necessary to differ with him on several fundamental points regarding his main conclusion that the animal was greatly overfed. During the period of 21 days of starvation the animal lost 5.15 kg. in body-weight and approximately 4 grams daily of nitrogen. During the second period, when the body-weight was being regained, Grafe's figures show that the animal received 2,243.9 net calories per day, and the nitrogen storage almost exactly compensated the nitrogen loss during the hunger period. The measurements of the metabolism during the hunger period, however, show that the total caloric loss during the 21 days was 17,403.5 calories.[1] Assuming that the caloric loss was the same, whether or not the animal was inside the respiration chamber, the daily loss would be not far from 829 calories.

During the second period of 7 days, when presumably excess food was given, it is reasonable to assume that the caloric output could not have been much less than 1,000 calories per day. Unfortunately no metabolism experiments after the ingestion of food were made during this period, but in the later experiments reported by Grafe, in which 2,600 or more calories were given per day, the caloric output was 1,200 calories or over; 1,000 calories is therefore a minimum rather than a maximum estimate. Accordingly, during these 7 days at least 7,000 calories would be required. Since the dog was given approximately 16,000 total net calories the amount available for replenishment of the lost tissue and fat in the body was about 9,000 calories, or about one-half that actually lost during the 21 days. Hence it is clear that it is illogical to reason that the animal body was in its original condition at the end of the 7-day period of feeding.

In discussing the metabolism in the 29-day period of greatest excess feeding, Grafe has compared it with the minimum metabolism of the

[1] Computed from table II on p. 18 of Grafe and Graham's paper (*loc. cit.*) as follows:

No. of days.	Calories per day.	Total.	No. of days.	Calories per day.	Total.
2	1055.7	2111.4	2	840.1	1680.2
1	935.0	935.0	3	762.2	2286.6
3	1008.0	3024.0	3	746.2	2238.6
3	793.5	2380.5	4	686.8	2747.2

dog on the last days of fasting, and has computed a value which shows he considers that if the animal weighed 20 kg., it would have a minimum caloric production of 822.8 calories. We believe that Grafe (like Benedict and Carpenter[1] of this Laboratory) has fallen into the error of using fasting values as distinguished from post-absorptive values for his basis of comparison. Benedict and Carpenter have discussed in considerable detail the error in using true fasting days for this purpose, since unquestionably the fast has, *per se*, a specific influence upon metabolism.[2] On this ground the basal value employed by Grafe is altogether too low; according to our computation, the total heat production of the dog would much more closely represent 1,200 calories per day during the period of heavy feeding. Since during this time Grafe states that 2,580 net calories per day were available, the excess would correspond to about 40,000 calories, *i. e.*, $2{,}580-1{,}200 \times 29=40{,}020$.

In the period of 11 days, when feeding with 1,660 calories per day, the maintenance requirement would, in all probability, be not less than 1,112 calories, as found by Grafe. Since this is a *nüchtern* value, during the feeding period it would unquestionably be somewhat higher, leaving the net surplus smaller. Disregarding this point, the net surplus is 548 calories, or a total for 11 days of 6,028 calories. In the next period of 19 days, the food was hardly above maintenance. Using the actual values obtained on those days when respiration experiments were made and the animal was without food in the stomach, the basal value can be assumed to be 1,030 calories. Since the daily energy intake during this period was 1,120 net calories, the surplus energy above maintenance would be only 90 calories daily, with a total excess for the 19 days of 1,710 calories. At the end of this period, therefore, we have a deficiency of 17,404 calories in the first 21 days to be made up, and available for this replenishment 56,758 calories. On this basis one can assume that 39,354 calories were stored in the body. On the basis of 9.5 calories per gram of fat this would correspond to approximately 4,143 grams or 4 kg. of fat.

We believe, however, that Grafe has made a fundamental error in assuming that the heat output of his dog outside the respiration chamber was the same as in the respiration chamber, since his own reports show that the respiration experiments were made at 22° C., while a very large part of the time the dog was in the cellar with a temperature of 15° C., and probably during the night with even a lower temperature. While exact quantitative data regarding the influence upon metabolism of temperature is still too scanty for most accurate computations, it has been the custom of physiologists for many years to use

[1] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918, p. 72.

[2] Grafe had good precedent for using the fasting value for a base line as in similar comparisons. Johansson, Landergren, Sondén, and Tigerstedt (Skand. Arch. f. Physiol., 1897, **7**, p. 29) had previously used values obtained with a man during a fast of 5 days.

the figure obtained by Rubner, which implies an increase in metabolism of approximately 3 per cent per degree centigrade.[1] We thus have a probable increase in metabolism of this animal on the days outside the respiration chamber of not far from 21 per cent or, roughly speaking, one-fifth. With a basal daily requirement of 1,200 calories, this would correspond to 240 calories per day. The four periods when excess food was given numbered 66 days, of which 12 were in the chamber. With an increase in the metabolism of 240 calories per day, there would be a total increase in the metabolism of $240 \times 54 = 12{,}960$ calories, or one-third of the excess computed by the above method. The excess calories, which amounted to $39{,}334 - 12{,}960 = 26{,}374$, if stored as fat, would correspond to about 3 kg. of fat or 15 per cent of the body-weight of the dog. It should be stated, however, that in a recent investigation by Zuntz[2] a series of experiments carried out with a dog at a temperature of 30° to 32° C. showed 44.4 calories per kilogram per 24 hours and another series at 15° to 16° C. showed 50.2 calories. This difference corresponds more nearly to 1 per cent per degree than to Rubner's figure of 3 per cent used in the above calculations.[3]

Since in our judgment the figures used in our recalculations for the basal metabolism and the estimates of probable energy requirements during repose are minimum rather than maximum, we believe that the experiment of Grafe does not positively prove the main point of his discussion, namely, that the dog, when given excess food, produced a sufficiently excess metabolism to counterbalance it.

A striking factor of Grafe's experiment must not be lost sight of in that throughout the entire period of realimentation there was a very great storage of nitrogen in the body. This storage, unaccompanied by a marked increase in metabolism, is, we believe, fully in conformity with the experience found by A. Müller[4] with man, in which 210 grams of nitrogen were stored without appreciable increase in the heat production per kilogram of body-weight. Although personal conversation with Dr. Grafe gives no clue as to the probability of an increased activity on the part of the dog when outside the chamber, it would appear as if the estimates for the energy requirement on the days when the animal was not in the chamber are too low. If this is the case and if correction is made for the erroneous basal value obtained after a period of prolonged inanition, we believe that the figures would not positively prove Grafe's main contention. The addition of a large amount of protein and certainly of some fat can hardly be accounted

[1] Rubner, Die Gesetze des Energieverbrauchs bei der Ernährung, Leipsic, 1902. Hári (Biochem. Zeitschr., 1914, **66**, p. 2) has pointed out that in many of Rubner's experiments the percentage difference per degree is 3 to 5 per cent.

[2] Zuntz, Biochem. Zeitschr., 1913, **55**, p. 341.

[3] This difference is at least in part explained by the fact that 32° C. is considerably above the so-called critical temperature for most dogs.

[4] A. Müller, Zentralbl. f. d. ges. Physiol. u. Pathol. d. Stoffw., 1911, N. F., **6**, p. 617. See also p. 29 of this monograph.

for wholly by the character of the material added during the first 7 days of feeding. Although the body-weight regained its original level, a computation of the caloric output of the animal and the character of the food shows that the organized tissue could not have been replaced during this period.

The values given by Grafe of the metabolism on hunger days during excess feeding in the third period show an average value of 1,030 calories. This is not far from that found on the first hunger day, and does not indicate an increase in the basal metabolism during this period.

In consideration of the strong probability that during the first 7 days with food the dog had not regained the original pre-fasting nutritional state, that the basal value selected by Grafe should have been that at the beginning rather than at the end of the 21-day hunger period, and that the metabolism in the cellar at 15° C. would be somewhat greater than in the respiration chamber at 22° C., we believe that one of Grafe's most striking series of experiments fails to prove his point.

Dengler and Mayer, 1906.—Two researches from von Noorden's clinic bear upon the relationship of the storage of nitrogen, increase in body-weight following excessive nitrogen ingestion, and the basal metabolism. Dengler and Mayer,[1] using a Zuntz-Geppert apparatus and a subject unfortunately not normal, made a 3-months' experiment with a nitrogen-rich diet. They found that in spite of an increase in body-weight of 13 kg. and a nitrogen storage of 371 grams, the oxygen consumption rose very slowly from 222 to 242 c.c. per minute; per kilogram of body-weight there was, if anything, a slight fall. The authors interpret this as signifying that the addition of nitrogen, even in this very large amount, could not have been in the form of active protoplasmic tissue.

A. Müller, 1911.—Five years later A. Müller[2] from the same clinic reported two researches, likewise with the Zuntz-Geppert apparatus, one with a subject who was perfectly healthy and the other with a greatly emaciated subject. In the first case, in an experimental period of about 2 months, 210 grams of nitrogen were added to the body during a period of surfeit feeding of 28 days. During this time there was an increase of 4 kg. in the body-weight, but the oxygen consumption rose only from 228 to 234 c.c. per minute. There was a slight decrease in the oxygen consumption per kilogram, ranging from 4.2 c.c. in the preliminary period to 4.0 c.c. in the surfeit feeding period. Müller concludes that when a marked storage of nitrogen is produced in a normal man by surfeit feeding with excess of both nitrogen and calories, the increase in the oxygen consumption is practically insignificant. On this point the experiment confirms fully the findings of Dengler and

[1] Dengler and Mayer, Zentralbl. f. d. ges. Physiol. u. Pathol. d. Stoffw., 1906, N. F., **1**, p. 228.
[2] A. Müller, Zentralbl. f. d. ges. Physiol. u. Pathol. d. Stoffw., 1911, N. F., **6**, p. 617.

Mayer. Müller concludes that the absence of an increase in oxygen consumption argues against a storage of active protoplasmic tissue and bears out the contention of von Noorden that the nitrogenous substance added to the body did not have the same biological properties as the original protoplasm.

With the second subject, who was much emaciated, with a height of 175 cm. and a body-weight of 46 kg., a storage of 198 grams of nitrogen was found 23 days after an operation for gastroenteritis. The increase in the oxygen consumption after the operation was very pronounced, rising from 180 to 231 c.c. The body-weight increased 5.5 kg. Since this increase in oxygen consumption took place a relatively few days after the operation and before there was a great storage of nitrogen in the body or appreciable increase in body-weight, the author argues that this was not caused by an addition of active protoplasmic tissue. He assumes that the increase in the oxygen consumption may be due to two possibilities: one, that during the hunger period the body was forced to limit its energy exchange and that with renewed feeding the energy thus s ved was expended; the other, that the transition from chronic undernutrition to normal conditions, especially to protein plethora, might lead to a temporary condition of stimulus to the cells and a transitory increase in metabolism. The first experiment of Müller is extremely difficult to understand. To secure so large a storage of nitrogen in the body with an apparently normal individual without altering the basal metabolism in the slightest is a striking observation. It is to be regretted that this experiment could not have been repeated under uniform conditions and thorough control.

Zuntz and Schirokich, 1912.—A series of experiments made by Zuntz and Schirokich[1] with Horace Fletcher, after a diet of potatoes and butter, has already been discussed in connection with experiments on this subject made at Wesleyan University and the Nutrition Laboratory. (See pages 7 to 10.)

Zuntz, 1913.—Zuntz,[2] in studying an animal that was underfed for a period of 13 months, found that the heat production per square meter of body-surface per 24 hours as computed on the Meeh formula (a method of computation that Zuntz himself considers somewhat doubtful) showed a falling off in metabolism from 931 calories when the dog weighed 10 kg. to 631 calories when the dog weighed one-half this amount. In spite of this fact, and in all probability because later when the body-weight had been reduced to 4.1 kg., the heat production per square meter of body-surface rose to 921 calories, Zuntz concludes that the theory of an adjustment of metabolism to an insufficient intake is not here substantiated. On the contrary, the opposite was demonstrated in the last few weeks of life, when there was a great rise in the metabolism.

[1] Zuntz and Schirokich, Separate from Med. Klinik, 1912, No. 32, 5 pp.
[2] Zuntz, Biochem. Zeitschr., 1913, **55**, p. 341.

Morgulis, 1914.—Morgulis,[1] carrying out the theories of Zuntz with whom he had worked in Berlin, reports results of an experiment on a dog which was given about one-third of the maintenance requirement in the diet. Prior to the reduction in the diet, the energy requirement was computed from the respiratory exchange to be 39.3 calories per kilogram per 24 hours. As a matter of fact, after the dog had lost 42.35 per cent of his original weight, the energy requirement was 43.6 calories, or 11 per cent more. Wholly inexplicable increases and decreases in metabolism were reported with the resumption of excess feeding.

Hári, 1914.—In a carefully planned series of experiments designed to eliminate the question of too low a temperature, Hári,[2] employing all of the usual Budapest accuracy of technique, studied the influence of chronic undernutrition on the metabolism, measuring the heat directly by means of the Rubner calorimeter. Although the experiments were somewhat complicated by the fact that, in the first place, the basal value was obtained in several days of complete fast, that milk was administered at times cold and at times warm, and that the actual amount of energy ingested averaged in all the series about 70 per cent of the maintenance need, Hári has drawn some important conclusions. Of special significance to us in this discussion, however, is the clear relationship he notes between metabolism and loss in nitrogen. The irregularity of his results he explains in part on the ground of individuality. The feeding experiments are usually of such short duration that it is difficult to distinguish between true starvation and the period of chronic undernutrition which in no case continued more than 9 days. Using the fasting days as basal values, Hári notes that when insufficient food is given, there is either a slight increase or a very slight tendency to a decrease in metabolism.

Loewy and Zuntz, 1916.—When the research reported by us in this monograph was more than half completed, we were fortunately able to secure a copy of the interesting article by Loewy and Zuntz[3] on the influence of war diet upon metabolism. This gives the results of experiments made in the spring of 1916 in which the investigators themselves were the subjects. Inasmuch as both Zuntz and Loewy had had their basal metabolism measured intermittently for a number of years previous, their probable basal values are significant and afford an excellent basis for comparison with the metabolism determined after two years of war diet.

The experiments were made with the Zuntz-Geppert apparatus and represent (in the case of Zuntz) 5 periods on 3 different days in May 1916. In the case of Loewy they represent 4 periods on 2 days, also in May 1916. Although Zuntz had lost considerable body-weight, never-

[1] Morgulis, Biochem. Bulletin, 1914, **3**, p. 264.
[2] Hári, Biochem. Zeitschr., 1914, **66**, p. 20.
[3] Loewy and Zuntz, Berl. klin. Wochenschr., 1916, **53**, p. 825.

theless the oxygen consumption and carbon-dioxide production were much lower per kilogram of body-weight than they were under pre-war conditions. The nitrogen excretion per day for Zuntz was relatively small, averaging not far from 6.50 grams. He computes that he was consuming approximately 51 to 52 grams of protein per day. Calculating the calories per square meter on the basis of the Meeh formula, he finds a reduction in heat production per square meter of body-surface corresponding to 7.3 per cent.

With Loewy the loss in body-weight was not so great as with Zuntz. The oxygen consumption per kilogram of body-weight and per square meter of body-surface was considerably reduced, being 12.2 per cent lower per kilogram of body-weight than formerly. Unlike Zuntz, Loewy lived upon a reasonably liberal nitrogen intake, since the nitrogen in the urine averaged 13.95 grams per day. Taking into consideration the nitrogen in the feces, it is computed that the nitrogen content of the food was the equivalent of 97.6 grams protein, or nearly twice that of Zuntz.

As an explanation of this lowering of metabolism, the authors suggest two possibilities: one, that there was a greatly reduced protein intake; the other, that with the loss of body-weight there was an even greater percentage loss of active cell substance. They conclude that the first of these suppositions is disproved by the results obtained with Loewy, who partook of a fairly liberal nitrogen diet. They finally conclude that the main cause of the reduction is the loss of active cell substance and, further, that even if there is a fairly liberal protein intake in the diet, insufficient calories will cause a great loss of active body substance.

Observations of the pulse-rate with Zuntz indicate a slight falling off in the 1916 series of experiments. During this series hemoglobin determinations were made and showed that the blood of both men indicated 110 per cent of hemoglobin on the Plesch hemoglobinometer.

It is thus clear that these two German scientists have definitely shown in their own cases measurably lowered metabolism as a result of the loss in weight incidental to the restricted diet of war times. In our examination of the earlier literature nowhere do we find such clear-cut statements with experimental evidence of the possibility of lowering the basal metabolism of man as are seen in these experiments of Loewy and Zuntz. The conflicting evidence noted throughout the literature for animals and for pathological cases with man is entirely absent in these two series of experiments.

Jansen, 1917.—The details of a second war-diet study, which was made by Jansen[1] and confirmed the findings of Loewy and Zuntz, came to our attention only when the report of our research had reached the first galley proof and hence too late for extended analysis. With 13 subjects Jansen studied the influence of a low-calorie diet upon the

[1] Jansen, Deutsch. Arch. f. klin. Med., 1917, **124**, p. 1.

nitrogen balance. All of the subjects, with the exception of two women in the group, had lost not far from 8 to 10 per cent in body-weight since the beginning of the war. The diet, which corresponded to the Munich ration in March 1917, had an energy value of about 1,600 (gross) calories per day, with a nitrogen content of approximately 9.7 grams (or 60.5 grams of protein) and contained 210 grams of carbohydrates. On this diet there was an average loss of nitrogen for the whole group of about 2 grams per day and an average loss in body-weight of 0.28 kilogram per day.

Respiration experiments were also made by the Zuntz-Geppert method with two subjects 23 and 26 years old, and of the same height and weight, *i. e.*, 174 centimeters and 56.1 kilograms. The basal heat production per 24 hours found in these experiments was 1,338 calories and 1,456 calories, respectively, while on the basis of per kilogram of body-weight it was 23.8 and 25.0 calories, respectively. Jansen points out that these values are low as compared with Magnus-Levy's values for normal subjects of like weight[1] and refers to the explanation of Loewy and Zuntz that this lowering in metabolism is due to the loss in active cell substance.

The basal metabolism of these subjects after a 3-day walking trip was again measured 12 hours after the last meal and after work and was found to be very greatly increased. The post-absorptive respiratory quotients for both subjects varied considerably, *i. e.*, from 1.29 to 0.78 and from 1.10 to 0.86, respectively, whereas in the previous series of experiments the quotient had averaged about 0.87. The oxygen consumption likewise varied considerably with one subject, and the lung ventilation was greatly increased. Jansen concludes that this amount of exercise, which would not be considered at all strenuous with a well-nourished man, produced with these subjects on restricted diet an extraordinary exhaustion and affected the respiratory exchange even after 12 hours of repose, this being shown by abnormally high values for oxygen consumption and the respiratory quotient. Unfortunately the respiratory data, judged in the light of our own observations, seem to be of uncertain value. Such astonishing alterations in the respiratory quotient and, indeed, in the basal oxygen consumption, are outside of our experience. It is to be hoped that the data will be supplemented by publications from other European laboratories where metabolism studies on the influence of a reduced diet have doubtless been made.

SUMMARY OF PREVIOUS LITERATURE.

In studying the results of previous investigations on undernutrition, it is of the greatest importance to note that there is a marked difference

[1] Calculation by the Harris-Benedict multiple prediction formula (Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919) gives 1,553 and 1,533 calories per 24 hours, respectively, *i. e.*, 16 and 5.5 per cent above the found values.

between complete fasting and chronic or partial inanition. The literature on complete fasting is fairly abundant and emphasizes sharply the fact that a complete fast is frequently accompanied by acidosis. This acidosis, it is believed, stimulates the cells of the fasting organism, producing a somewhat higher metabolism than might otherwise exist. Hence the subject of complete inanition is hardly touched upon in our citation of the literature.

Temporary complete absence of food from the stomach must not, however, be confused with complete fasting. As has been shown, the ingestion of food produces a definite effect upon metabolism. Any food in the stomach results in an increased heat production, food ingestion being second only to muscular work as a factor for producing an increase in the metabolism above basal. In looking over the literature on the subject of metabolism during undernutrition, one finds only too frequently that confusion has arisen from the fact that writers have included in the basal measurements the excess metabolism due to the stimulus of food. The instances are rare in which clear-cut evidence is given regarding the basal metabolism at different nutritional levels, for obviously an experiment which includes the activity incidental to food ingestion can throw but little light upon the actual basal requirements. It is quite probable that this practice is due in large part to the original conception of Rubner that when food is given below the maintenance requirement the so-called specific dynamic action of food does not appear.[1] Modern experiments have shown that this is not the case and that the ingestion of food always stimulates metabolism.

For accurate comparative measurements it is possible to use only those values obtained when the subject is in complete muscular repose and when there is no food in the alimentary tract, *i. e.*, with men usually 12 hours after the last meal, the so-called "post-absorptive condition." On the other hand, the use of basal values obtained in one, two, or more days of complete fasting is distinctly erroneous. All of the earlier discussions of the influence of partial nutrition upon the basal metabolism, which use basal values obtained on days of complete fasting, must therefore be considered as fundamentally incorrect.

The evidence on the gaseous exchange during undernutrition, as found in previous literature, is very conflicting. No better illustration of this uncertainty can be given than to point out the fact that writers may interpret exactly the same data in two strikingly different ways. Thus we have already shown that the data obtained by Falta, Grote, and Staehelin[2] are, in our judgment, not justifiable as proof of a depression in metabolism. On the other hand, the metabolism measurements on Caspari's vegetarian,[3] according to Staehelin,[4] show no

[1] Rubner, Zeitschr. f. Biol., 1883, **19**, p. 348.
[2] Falta, Grote, and Staehelin, Beitr. z. chem. Physiol. u. Path., 1907, **9**, p. 333.
[3] Caspari, Arch. f. d. ges. Physiol., 1905, **109**, p. 473.
[4] Staehelin, Deutsch. med. Wochenschr., 1909, **35**, p. 610.

reduction, while Zuntz[1] and Caspari[2] both specifically state that owing to the restlessness of the subject they are certain that the basal value has not been found. It thus follows that if the basal value on this man had been found, depressed metabolism would surely have been indicated.

If it were not for the specially clear evidence obtained from the recent experiments of Loewy and Zuntz, little of positive assurance could be derived from the literature. These experiments, taken in connection with the evidence presented by many of the earlier workers, indicate that with undernutrition there is a loss in weight and a tendency to a reduced metabolism. With a loss in body-weight, one would expect to find a lowering of the total metabolism, but with Loewy and Zuntz, and, to a certain extent, with Jansen's subjects, the metabolism per kilogram of body-weight was likewise distinctly lower during the reduced diet, thus showing that the basal metabolism was specifically lowered. This, they believe, was due to the loss of organic tissue. We thus have here a clear indication of a lower plane of nutrition. Such a change in nutritional level is also indicated by Rubner in his statement in enunciating his law of surface area that animals compared should be in the same state of nutrition.

On the basis of this evidence, one would expect to find, when examining the basal metabolism of normal men and women, that individuals of very low weight would have a low metabolism, both per kilogram of body-weight and per square meter of body-surface. In fact, data show clearly that thin people have a higher metabolism per kilogram of body-weight and as high a metabolism per square meter of body-surface as have fat people of the same age,[3] for while Means[4] contends that the heat per square meter of body-surface is the same with fat people as with the Du Bois normals, the obese usually give very low values per kilogram of body-weight. Furthermore, athletes (from whom presumably a large amount of body fat has been removed by training) show a higher metabolism than normal, although this is in large part due to the stimulus of cellular activity incidental to excessive muscular exercise. Considering individuals in general, therefore, the composition of the body appears to be of appreciable significance, and one may not state that 1 kg. of fat has the same heat-producing power as 1 kg. of active protoplasmic tissue. Consequently one would reason that when fat is lost, there would be a specific increase in the heat production per kilogram of body-weight. Quite the contrary was observed by Loewy and Zuntz.

On the other hand, aside from fat people, diabetics subsequent to the fasting treatment, and a man fasting 31 days, we have found no class of

[1] Zuntz, Biochem. Zeitschr., 1913, **55**, p. 342.
[2] Caspari, Arch. f. d. ges. Physiol., 1905, **109**, p. 564.
[3] Benedict, Journ. Biol. Chem., 1915, **20**, p. 282.
[4] Means, Journ. Med. Research, 1915, **32**, p. 121.

individuals having a low metabolism per kilogram of body-weight or per square meter of body-surface. While we are convinced that the so-called law of surface area is not so rigid in its application as its warmest advocates would like to believe, the numerous deviations from this law do not provide evidence as to any particular class or group of individuals with a low metabolism, although the high metabolism of athletes has been experimentally demonstrated.

PURPOSE AND PLAN OF PRESENT RESEARCH.

Since one or two classes of individuals, even though abnormal, show a lowered basal metabolism mainly as the result of a considerable degree of emaciation, it is a legitimate question as to whether or not a dietetic régime which leads to a moderate loss of flesh in normal subjects may not result in a lowered basal metabolism. Undernutrition is caused by a deficiency in food intake; this deficiency may be due either to a deficiency in protein or in calories in the diet.[1]

Protein intake.—The problem of a reduced food intake has received attention from physiologists for several generations, but interest has been centered for the most part upon the possibility of lowering the intake of protein. As the result of the heroic experiments of Professor Chittenden and his school at New Haven, the idea has gained credence (certainly with the American public and practically all physiologists) that a large protein intake is neither necessary nor desirable; on the other hand, that there should be an extensive reduction in protein is by no means accepted by all. One may sum up the situation by stating that the experiments of Professor Chittenden have unquestionably had a strong influence upon physiological thought in favor of a material reduction in the protein intake. It is safe to say that to most minds the reduction in protein is desirable mainly from an economic standpoint rather than from absolute physiological danger due to the ingestion of so-called "enormous" amounts; but it is undoubtedly true that a reduction in protein may certainly be made without danger. The most important point, however, at the present time is not the question of protein intake, but that of the total energy intake.

Energy intake.—It is a common household observation that people eat too much, the popular quantitative expression being that "people eat twice as much as they ought." Almost every household has its dietetic peculiarities, one individual eating very heartily, while another is said to eat "hardly enough to keep a canary alive." Yet careful studies of groups of individuals living under the same conditions show that ordinarily the total food consumption for like groups of individuals does not vary widely, and it would thus appear that the intake of

[1] Although without bearing on this research (see page 260), the detrimental effects of a deficiency in the so-called food accessory substances must not be overlooked in any basic consideration of undernutrition.

food is adjusted in general to the demand of the body for fuel. This is best shown by the fact that, after maturity, the body-weight for the majority of individuals does not change widely for periods of years. Since the law of the conservation of energy obtains in the human body, the food intake thus corresponds on the average to the demands for energy. When food is absorbed, it can be disposed of in but two ways, either burned or stored as fat. If stored as fat, the weight would increase; if burned, the metabolism has been increased. Since the basal metabolism of an individual remains reasonably constant, any great increase in metabolism must be due to an increase in activity, *i. e.*, muscular work. Consequently experimental evidence points to the fact that the ordinary dietetic habits of a community are usually adjusted to its needs for metabolic level and muscular activity.

Recently the food stringency in Germany has thrown new light upon the possibilities of establishing lower nutritional levels by reducing the intake of food and lowering the body-weight.

HISTORY OF INCEPTION OF RESEARCH.

In the spring of 1917 it was the good fortune of one of us to have a long conference in Philadelphia with Professor Alonzo E. Taylor, who had but recently returned from Germany. Professor Taylor was thoroughly conversant with the food situation in that country, had discussed the subject *in extenso* with eminent German physiologists, and hence was specially provided with information as to the present dietetic habits of both the civilian population and the army in Germany.

According to Professor Taylor, it would appear from the ration cards and from the computations of the best hygienic and dietetic experts that the German civilian population were securing not more than 1,800 calories per man per day. The German army ration approximated 3,200 calories per day. In an article laying particular emphasis upon the rôle of acid and alkali-forming ingredients in the diet, Ragnar-Berg[1] gives a tabular presentation of the army ration in Germany as well as that of the hard worker and the civilian. These values bear out quite closely Professor Taylor's estimates. Aside from results obtained in the study made by Loewy and Zuntz,[2] and Jansen,[3] previously referred to, and with which we were unfortunately not earlier acquainted, the reports from Germany lack that scientific verification that one would prefer to have, but the possible adjustment to a lower nutritional level seems sufficiently established to be accepted as highly probable. The fact is established, however, that as a result of this reduction in diet, the obese are now rarely seen in Germany, that the German civilians have lost considerably in body-

[1] The original place of publication in Germany is not given, but the article is abstracted in the Bull. de la Soc. Sci. Hyg. Aliment., 1918, **5**, p. 652.
[2] Loewy and Zuntz, Berl. klin. Wochenschr., 1916, **53**, p. 825.
[3] Jansen, Deutsch. Archiv. f. klin. Med., 1917, **124**, p. 1.

weight and are thin and well trained down. In view of the experience of the German nation, it seemed feasible to alter experimentally the food intake and in consequence probably alter the nutritional level.

It was first thought that such a study could be made with a group of men who had already considerably reduced their body-weight by dietetic alterations. Athletes who had suddenly lost much flesh in preparation for an athletic contest were first considered, but it was decided that athletes are trained not only to lose flesh but at the same time to retain their excessive strength. Dr. George P. Denny, who was at this period a collaborator at the Nutrition Laboratory, then offered to secure the services of a number of coxswains from the boat crews of Harvard University. Such men should be well suited for observations of this kind, as it is necessary for them to train down to a low body-weight, but at the same time no special strength is required in their duties. Simultaneously with the inception of this project, war was declared between the United States and Germany and the athletic plans of Harvard University were entirely revolutionized. It was therefore necessary to give up the idea of a research with coxswains and seek elsewhere for the ideal subjects for the contemplated study. It was finally decided to secure a number of normal individuals and study the metabolism during a long period of low food intake.

GENERAL PLAN OF RESEARCH.

To have such a study of direct practical value, these men must be living normal lives and carrying out their regular activities in the community. Furthermore, they should be of normal weight, rather than obese, to avoid introducing the pathological factor of obesity. In Germany there was at first a somewhat acute period of loss in weight, caused by the sudden stringency in food materials and the inability of the people as a whole to adjust themselves rapidly to the lowered food intake. There was then a period in which the redistribution of food made it possible to hold the body-weight at the lower level. Our study with the group of normal men was therefore made along two definite lines, *i. e.*, to determine the physiological effect of a pronounced reduction in diet under the following conditions:

(*a*) During the period of loss in weight when the energy of the diet would be supplemented to a considerable extent by drafts upon body material.

(*b*) During the period of subsequent feeding with a diet selected to maintain the body in equilibrium at the lower body-weight.

During such weight reduction previous experience with fasting men had shown that there would be in all probability a loss in nitrogen, certainly a loss in body-fat, and probably a somewhat lower heat output. Hence it was recognized that the following special records should be made:

First, the total caloric intake of each individual should be obtained, both during the period of loss in weight and especially during the period of maintenance at the lower body-weight.

Second, the total changes in body nitrogen should be determined by establishing a continuous nitrogen balance until equilibrium was subsequently found at the lower weight level.

Third, there should be records of the body-weight, with observation of the fluctuations and the causes therefor, recognizing the fact that sharp fluctuations in body-weight may in large part be attributed to changes in the water content of the body.

Fourth, a record should be made of the general physical well being, this to include measurements of strength.

Fifth, since it was highly important that possible impairment of the intellectual and physical ability should not be overlooked, continuous and careful records of neuro-muscular processes should be obtained.

In connection with such a research, the following questions naturally suggest themselves:

(1) Is it possible to alter the basal metabolism by a reduced ration?

(2) Can the body be held in nitrogen and carbon equilibrium at the lower level?

(3) If such a lowering in basal metabolism is obtained by a reduction in diet, will the lowering be proportional to the reduction in weight, that is, if there is a loss of 10 per cent in body-weight, will the basal metabolism be 10 per cent less than the normal metabolism or will the basal metabolism per kilogram of body-weight be unlike at the two nutritional levels?

(4) Since the body material lost would presumably be in greater part fat, and thus supposedly inactive in metabolism, will the basal metabolism increase with the loss in weight, as would be expected, or will it decrease?

(5) Will superimposed muscular work be done at a higher or lower cost of energy at an altered level of basal metabolism?

(6) Will the stimulating effect of foodstuffs, primarily that of protein, be the same with reduced body-weight as with the normal body-weight?

As the result of our research, we were able to make material contributions on the first five problems, and suggestions on the sixth may also be found in our data.

The larger portion of the preliminary plans for this research were made in conference with our colleague, Dr. Thorne M. Carpenter, who had expected to be actively associated with this work. An unfortunate typhoid fever infection in the early fall made it necessary for him to withdraw completely from the investigation, although in the last few weeks he kindly cooperated in some of the temperature and pulse measurements. His absence from the Laboratory was keenly felt by all, since we had greatly counted on his counsel and cooperation. Fortunately, the entire manuscript has had his critical reading.

REDUCTION OF BODY-WEIGHT OF SUBJECTS.

In our research on the effect on the metabolism of reducing the body-weight by alterations in diet, several plans for reducing the weight of the subjects suggested themselves. The total weight reduction was tentatively set at 10 per cent in the belief that a 10 per cent loss would be of sufficient magnitude to show positively any changes in the metabolism, while a percentage less than this might not be measurable with

many of the factors. A greater reduction in weight would prolong the experiment and require greater dietetic control; the amount of discomfort might be taken as roughly proportional to the degree of loss.

Previous experience with fasting men has shown that it is perfectly safe and not productive of great discomfort to fast completely for several days. While the loss of 10 per cent could be secured by complete abstinence from food (judging from our experience with the man fasting for 31 days this loss could be obtained in a period of complete fasting of 14 days), it was recognized that it was impractical to ask a group of men to sacrifice their entire time to a test of this kind and to undergo a complete deprivation of food for 14 days. Consequently it was considered best to produce the loss in weight by the administration of a diet so reduced that there would be each day material drafts upon body fat. It was therefore tentatively proposed that the ingesta should be approximately from 50 to 70 per cent of the actual food requirements.

After the reduction in body-weight of 10 per cent had been reached, the basal ration was then to be supplemented in each case with sufficient energy in food materials to hold the body-weight at the lower level and an attempt made to obtain nitrogen equilibrium as soon as possible. Carbon equilibrium or energy equilibrium would be indicated by constant body-weight over a period of weeks; nitrogen equilibrium would be shown in the usual manner by the balance between the nitrogen in the intake of food and the nitrogen in the feces and urine.

From our experience with fasting men and from the experience of this Laboratory in conjunction with Dr. E. P. Joslin in studies of diabetics with their extreme losses, it appeared perfectly safe to attempt an observation of this kind, since the reduction in body-weight was to be but 10 per cent or slightly more.

SELECTION OF SUBJECTS.

For the study of so important a problem as the influence of undernutrition upon basal metabolism and vital processes in general, it was essential that the subjects of the research should be men rather than animals, especially as the nation is not so much interested in the better utilization of feeding stuffs for animals as it is in the utilization of food for man. This naturally increased our responsibility and financial obligations, as only those having actual experience with this type of work can realize. Investigators who work entirely with small animals and domestic fowl can have little conception of the perplexities which arise in working with a considerable number of adults.

Observations on one man may be considered in general as typical of observations on men as a whole until striking abnormalities or variations are shown. Thus the ingestion of 100 grams of sugar produces a

rise in metabolism with every man. The ingestion of 200 grams of beef likewise produces a rise in metabolism with every man. On the other hand, when the quantitative relationship between the amounts of sugar and beef ingested and the rise in metabolism are to be considered, one may then state properly that experiments on one man are not permissible for a fundamental generalization. It has been the custom of this Laboratory to recognize the legality of this latter contention and a large number of experiments are always made in all our researches. In fact, the Laboratory has even been charged with making too many experiments.[1]

It is evident, however, that with a problem of such national importance, the study, to be of practical value, must be carried out with a sufficiently large number of men for the results to be reasonably conclusive. As our research on the effect of a reduced diet would probably continue 3 or 4 months, it was necessary to select enough men to allow for all exigencies which might arise, including possible demands for national service. After careful consideration it was decided that the investigation should begin with not less than 12 subjects.

To secure results of general applicability to the civilian population of the United States, an ideal study would include observations not only upon men but likewise upon women and children, but it was believed that if one selected class was followed with great care, it could be reasonably inferred that the general picture obtained would probably in large part apply to other groups. Hence groups of young men were decided on, these to be preferably beyond the age of growth. While in the strictest sense growth persists until 28 years of age, which is shown to be the average age for maximum height, we considered that college students would meet the requirements perfectly.

ESSENTIALS FOR SELECTION.

In the selection of these men there were several essentials to be observed. These may be outlined as follows:

(1) *They should be in good health.*—It has been our custom to consider subjects "presumably in good health" as normal individuals, from whom general deductions could be drawn. In this case we felt it desirable to qualify the clause "presumably in good health" with a certification by a responsible physician after careful clinical examination. With these precautions we are able to state that our subjects were normal young men and in good health. While it was the intention to avoid the age of growth and we supposed that our young men were all of legal age, *i. e.*, 21 years or over, in certain instances men as young as 19 years were inadvertently selected. Still we think this does not vitiate our general contention that in this study we are not dealing with the growth factor in any sense.

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[1] Lindhard, Arch. f. d. ges. Physiol., 1915, **161**, p. 345.

(2) *They should be responsible, cooperating, and truthful* men, for in a study continuing over a period of 3 or 4 months and involving the strictest fidelity to general plan, especially in regard to dietetic habits, the whole success of the venture would, in the last analysis, depend upon absolute veracity.

(3) *They should be volunteers*, for men assigned to such a research would not enter into it whole-heartedly. For this reason soldiers detailed for such duty, even those belonging to a medical ward, would not be likely to give the cooperation we desired. For many physiological studies prisoners or other institutional inmates would prove ideal subjects, but would not be suitable in this case, if the service were compulsory; if prisoners volunteered in response to such rewards as an abatement of sentence, their use would then be justifiable.

(4) *The subjects should not consider themselves obligated to volunteer*, or if they felt they were forced into a test of this character, they could not cooperate to the extent that the investigations demanded.

(5) *They should be willing to undergo a certain amount of privation and discomfort*, for there would be more or less restriction as to the usual habits, dietetic customs, social environment, etc.

(6) *They should preferably be living under community conditions*, such as dormitory life, with regularity of daily routine. This would assist materially in the dietetic control and the collection of urine and feces required in the daily routine.

(7) *They should be willing to serve as subjects for several months*, since the time, labor, and money investment for each man would increase as the research progressed and his loss as a subject be more serious if his individual observations were incomplete.

(8) *They should have a unity of interest.*—In military phraseology, the "squad" system was emphasized. The personal influence was made a feature of the entire research, with the idea that each man would not only perform his own part in the observations successfully, but that his moral support would render material assistance to each of his associates.

(9) *The subjects should be as varied in type as practicable.*—While not all types of physical and intellectual activity could be studied in the research, yet since the average man is more or less intellectual, and possesses a fair degree of physical development, it was desirable to select as nearly as possible a group equally divided between those who paid special attention to physical development and those whose activities were more exclusively intellectual.

FINAL SELECTION OF MEN.

The finding of men who should have all of these qualifications required careful consideration of various possibilities. After a period of several months, it was finally decided that a group of students could best be chosen from the International Young Men's Christian Asso-

ciation College in Springfield, Massachusetts. The desirability of such a selection is shown by the following facts:

In the first place, the students in this college are all professing Christians, their admission to the institution being dependent upon high moral character combined with intellectual and physical fitness. The men would thus be clean-lived and with good histories as to excesses of all kinds. The question of tobacco and alcohol would also be eliminated and a good physical condition be assured. The ethical standards are high and the honor system obtains in every phase of the college life.

Still another reason for selecting students from this college is the unusual interest in physiological problems throughout the college body. This is due in large part to the active interest in and contributions to physiology made by Professors J. H. McCurdy and Elmer Berry, whose personal cooperation and assistance in many details at Springfield were admittedly great assets in beginning an investigation of this kind. The contributions of both these gentlemen to physical education are well known.

It was a source of great regret to us that, owing to the pressing demands of the Young Men's Christian Association under the present war conditions in France, Professor McCurdy left America for that country before our investigation actually began. This was not only a great loss to us in carrying out the investigation, but necessitated a considerable addition to the already burdensome administrative work of Professor Berry, which prevented him from giving so large an amount of time to the research as he otherwise would have done.

Notwithstanding the fact that the distance from Boston (100 miles) required a large expenditure for transportation of apparatus, samples, and subjects, the wisdom of selecting men from this institution was repeatedly proved and never questioned during the research. At no point were we disappointed in the group of men selected, in their fidelity and interest, or in the general spirit of cooperation and friendliness exhibited by the teaching staff of the college, especially by President Laurence L. Doggett. Our obligations to Professor Elmer Berry are beyond adequate expression. The keen cooperation of Professor A. G. Johnson in a number of the measurements of physical achievement was likewise highly valued. A factor of most vital importance was the assistance of Chef Arthur M. Hall, of the Students' Dining Association, whose faithfulness and good nature under most trying and perplexing circumstances made possible a dietary control that we believe is rare in the annals of physiological experimenting.

Although the decision to undertake this investigation was made in the spring of 1917, it was of course impossible to begin the observations until the opening of the academic year in the fall. Throughout the summer much time was given to a further elaboration of the program of the research, to the construction and testing of apparatus, and to

the preparation of material for transportation to Springfield. Considerable anxiety was felt as to the possibility of carrying out the research, owing to the constant reports during the summer of low registration and probably small attendance at the college on account of the drafts for military service and the demands for graduates and undergraduates for Y. M. C. A. work in the field. After a year's experience with these men, one can easily see why the demand should have been so great. As a matter of fact, it was not until the opening of the college year that we were confident that a sufficient number of students would be available from whom to select subjects for the research.

In a general address at the opening of the college, the plan for the investigation was outlined and volunteers were asked for from the student body. Sixty-three men (considerably more than half of those attending the meeting) offered their services. Detailed explanations were given to these men as to the time required and the specific demands which would be made upon them. When it is remembered that many of those volunteering relied upon outside employment for their support in college and many of them had previously obligated themselves for such employment, it was surprising to find that after this explanation of the requirements there still remained 34 men who were ready to join the "squad." It must be emphasized at this point that these men were, first, college students with all the obligations of college attendance, and second, volunteers for experiments of this kind. From the 34 men remaining a careful selection was made, chiefly on the advice of Professor Berry, of the 12 men to serve as "Squad A." Of these 12 men, 5 were taking the secretarial course and 7 the physical course.[1]

To illustrate the spirit obtaining in the college, the fact is of interest that before the final selection was made, many of the volunteers specially requested that they be allowed to serve. After the selection a number of the men were obviously disappointed, for they felt that it was an opportunity to be of real service in undergoing some privation for the sake of science and of supplying important information to the nation in a crisis. The 22 men remaining thus provided excellent material as a reserve for possible substitutes in Squad A and for the selection of subjects for the second squad (Squad B) and assured the carrying out of the original plan of research.

COLLEGE STATUS OF MEN IN SQUAD A.

At the time the call was made for volunteer subjects, it was clearly explained that no college credit would be given for service in the experiment and it was emphasized that the work would require considerable time and attention from those who entered. It is reasonable to believe that under these conditions those who offered themselves would be serious-minded and such as had previously done at least fairly well

[1] This refers to the final personnel of Squad A, and includes Kontner but not Fretter. Of Squad B, 3 were taking the secretarial course and 9 the physical course

with their college studies and who might feel that they could assume the added work without prohibitive difficulty.

In selecting the personnel for Squad A from the volunteers who offered, preference was given to those in the senior class and to men who were of age. No stress was placed on scholastic standing, but it is not surprising to discover that the men of this group have college records which average slightly higher than those of their fellow classmen. The college grades have been carefully investigated in reference to this matter, the college registrar, Mr. John F. Simons, kindly cooperating in this as on many another occasion. The record sheets were placed at our disposal and from these the grades were transcribed and later studied. Eight of the men of Squad A (Brown, Canfield, Gardner, Gullickson, Moyer, Peckham, Tompkins, and Veal) were seniors.[1] Their average college grade, which includes all the term grades given in all the subjects which these men had taken at the International Y. M. C. A. College prior to September 1917, was 88.6 per cent. There were 31 other men in the senior class. The average grade for the latter group, computed in identically the same manner as for the men of Squad A, was 86.3 per cent. Three of the men of Squad A as finally made up were sophomores (Montague, Peabody, and Spencer). The average grade of these in courses taken before September 1917 was 84 and that for a group of 27 fellow classmen was 83 per cent. The differences between averages, while in favor of the Squad A men, are rather small and would indicate that our subjects were not so much above the average student in ability that they could do average work without effort. Any prolonged and serious interference with mental efficiency would therefore probably show itself in their college class work.

EVIDENCE OF DIETETIC CONTROL.

Before taking part in the research, each member of both squads was requested to sign the following affidavit:

"The undersigned, being acquainted with the requirements imposed upon all who volunteer to serve as subjects in the war-ration research, promises so far as lies in his power to lend his entire cooperation in minutely and faithfully acquitting himself of all the duties required of him personally for the successful achievement of the research. He further promises his uninterrupted services and cooperation as subject during the entire period of observation. He promises not to eat or drink anything away from the training table, unless special provisions are previously made therefor. If, inadvertently, this rule is broken, he will immediately report all details of the breach, to assist in attempting to correct the error. He will not seek to be released from his responsibilities as subject until the completion of the research, unless compelled to do so by major causes, such causes to be declared justifiable by a

[1] Another man, Fretter, was also a senior, but as elsewhere stated, his service in Squad A was very short. Since no scholastic results can be given for him when on diet, he has been included in the larger group of seniors. Kontner, who replaced Fretter in the squad, had special college work and there was no group with which he could well be compared.

committee of the faculty. He furthermore understands that at the conclusion of the research he will be requested to make affidavit, on his honor as a gentleman, to the fidelity with which he has lived up to the regulations of the research, the careful reading of which is attested by signature to this instrument."

Although there were certain physiological controls on the strict adherence to diet, in the last analysis it would be necessary to rely upon the honor of the men. With the magnificent college spirit and the high ethical standards obtaining in this college, one might at the outset assume without further evidence that the greatest fidelity and honesty of purpose would be assured. According to the honor system which was in active operation in the college, a subject would be in honor bound not to violate the conditions of the experiment and likewise in honor bound to report any known violation by fellow members of the squad.

The importance of absolute fidelity in the dietetic control can hardly be overestimated. For instance, if the record of the protein intake were not complete, due to the fact that the subject took excess food away from the training table, the nitrogen balance, which has assumed much prominence in this research, would be invalidated. Similarly if there were an incomplete collection of urine, the computation of the nitrogen balance would not be accurate. If, however, there were marked fluctuations in the nitrogen excretion in the urine which could not be accounted for by similar fluctuations in the nitrogen of the diet, it would be reasonable to suspect an infringement of the rules. Of course it would have been possible for a subject to take excess protein food and designedly give incomplete returns for the total urine excreted or report that the urine was lost, but we are certain that no such instance occurred.

It is, however, with the energy balance that the personal veracity of each man is the more important, for an energy balance computed from the measurement of the intake of food and the output in the urine and feces can have no value without the assurance that the measurement of the energy in the diet agrees with the actual daily intake. Without this assurance, the whole study from the standpoint of energy, which is of fundamental importance in this research, would be useless. Thus we see that the honor, personal integrity, and fidelity of our subjects are the greatest assets that we could have in the selection of a group of men for this type of experimentation.

We should here assert our belief in the honor and fidelity of these men. Throughout the entire four months of the investigation there was but one suspected violation of the rules. This was early in the series when there was a marked increase in the nitrogen excretion on one day with one subject, which was coincident with certain social functions. This led us to consider the possibility that the man had violated his agreement, although no report was made of it. Instead of making the direct charge, we argued that if he had violated the agree-

ment once and it was unnoticed, he would certainly repeat the offense. It is a great pleasure to record that there was no other instance in which there was even a suspicion of an infringement. We now believe that the apparent violation of the rules was due to a gross error in reading the volume of urine. As stated earlier, these men were all professing Christians, but the men either refused to take the sacrament at church or else took it and reported the fact in accordance with the agreement in the affidavit. Our own personal belief is that none of the 26 men wilfully infringed the rules at any time during the research. The number of instances in which the students reported minor violations of the rules were so rare as to lead us to believe that throughout the entire period the 26 men used in the research considered it to be a serious phase in their academic life and lived up to the high standards of the college. We place special emphasis upon this point, as it indicates that the selection of subjects from the college body of the International Y. M. C. A. College at Springfield, with the high ethical standards obtaining, the honor system, the unusual interest in and appreciation of physiological experimentation and the importance of service in the national food crisis, was particularly fortunate.

PERSONAL HISTORIES.

The brief personal history for the individual subjects which follows includes the full name, date of birth, home address, age at the beginning of the experiment, height, initial nude weight, and the result of the preliminary physical examination by Dr. Walter H. Chapin of Springfield, Massachusetts. Under "personal data" are included various miscellaneous incidents during the progress of the experiment, more especially those relating to the physical condition of the subject. The physical characteristics of the family of the subject are given under "family history." The course taken in college and the physical activities of the subject are likewise included in the data. The personal histories for Squad A are naturally more detailed than those for Squad B. *For subsequent reference in a large number of tables, abbreviations of the names of the subjects seemed essential. Consequently throughout the book, the men are usually designated by the first three letters of the surname in each case.* The personal history of each man is given under this arbitrary designation for ready reference.

SQUAD A.

BRO.

George A. Brown; born Sept. 27, 1891; home Rochester, N. Y.; age 26 years; height 167 cm.; nude weight 61.75 kilos. *Medical examination:* Oct. 2, 1917, negative. *Family history:* Only child; father and mother thin; no tuberculosis. *College course:* Physical. *Personal data:* Dislocated toe in playing football; in hospital night of Nov. 1–2, 1917. Under ether 7 to 9 p. m. while toe was set; no ill effects except slight nausea, but no food ejected in vomiting. No supper Nov. 1; breakfast at hospital Nov. 2; returned to

training table for dinner on that day. On crutches about 4 days; foot in cast 11 days; unable to exercise much for about 3 weeks after accident. Looseness of bowels Dec. 10. *Physical activities:* Captain of second soccer team. According to personal estimate Sept. 27, about 25 hours a week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Oct. 23, seen running up dormitory stairs two steps at a time and whistling; Dec. 4, observed in gymnasium class by one of us and doing as well as average of class. Feb. 1, at 12 noon, "chinned bar" in gymnasium 12 times, equaling previous best record which was two years before. Same date, took part in arm-holding contest, continuing for whole period of 1 hour.

CAN.

KENNETH B. CANFIELD; born March 6, 1892; home Somerville, Mass.; age 26 years; height 177 cm.; nude weight 79.75 kilos. *Medical examination:* Nov. 21, 1917, negative. *Family history:* Mother somewhat stout; maternal grandfather stout (weighed 200 pounds); subject resembles mother; no tuberculosis. *College course:* Secretarial. *Personal data:* Oct. 24, tired and tooth ached. Oct. 27–28, severe headache when he went into chamber at beginning of experiment. Nov. 4, complained of being cold and of low body temperature. Nov. 16, more or less stiffness, particularly in muscles of thighs. Nov. 27, light case of tonsilitis; throat red, congested, and several patches on tonsils; tonsils somewhat swollen; temperature sub-normal; chilly; well Dec. 5. *Physical activities:* Sept. 27, according to personal estimate, about 12 hours per week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Nov. 11, took 4-mile walk. Jan. 26, seen running upstairs. Feb. 1, at 12 noon, "chinned bar" in gymnasium 5 times; probably this his best record. Same date, took part in arm-holding contest for 37 minutes of the 1-hour test; third man of Squad A to fall out.

FRE.

LESTER F. FRETTER; born Nov. 18, 1892; home Cleveland, Ohio; age 25 years; height 167 cm.; nude weight 57.5 kilos. *Medical examination:* Oct. 2, 1917, negative. *Family history:* No record. *College course:* Physical. *Personal data:* Oct. 20 developed pain and soreness in epigastrium; pain relieved on eating. Examined by Dr. Chapin Oct. 22; possibility of gastric ulcer; again examined by Dr. Chapin Oct. 24, who reported the subject was undoubtedly undernourished for the amount of work he was doing in college and advised his being relieved from squad duty; dropped from squad Oct. 25; last day at training table Oct. 24. *Physical activities:* According to personal estimate Sept. 27, spent about 25 hours a week in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Led gymnasium classes at high school.

KON.

EVERETT R. KONTNER; born Feb. 7, 1898; home Nelsonville, Ohio; age 20 years; height 168 cm.; nude weight 69 kilos. *Medical examination:* Not made. *Family history:* Mother has slight tendency to obesity; no tuberculosis. *College course:* Physical. *Personal data:* Joined Squad A Oct. 30, 1917, as successor to *Fre.* Nov. 16, nasal catarrh with some headache for two days preceding. Nov. 18, in playing football, muscles of left arm strained and injury to nose, possibly nose broken. Nov. 19, reported nose not broken and accident not serious. Nov. 30 entered hospital for removal of part of turbinated bones, tonsils, and adenoids, and for straightening of septum of nasal cavity; discharged from hospital evening of Dec.

1; received treatment until Dec. 17; wore solid rubber tube in left nostril from Dec. 3 to about Jan. 16, to hold septum in position; unable to secure perfect closure with nose clips in portable respiration apparatus experiments until about Dec. 11, when physician allowed him to remove tube during the experiments. Dec. 9, headache. Dec. 12, felt weak. Dec. 13, temperature (oral) 103° F. in morning; excused from portable respiration apparatus experiment and sent back to bed; temperature at 9^h30^m a. m., 101.2° F., with severe headache and fever, probably due to infection of frontal sinus as result of nasal trouble; fainted while telephoning to physician. Dec. 14, felt much better, though a little light-headed; no fever; pulse-rate, 50; came to table for dinner. Dec. 16, headache in morning. Dec. 17, well; little looseness of bowels. Dec. 29, after a week's illness with apparent bowel infection, treated by physician, who diagnosed it as intestinal grippe. Jan. 22, more turbinated bone removed from left nostril. *Physical activities:* On football team; excused from game Nov. 2 because his play was weak. Suggestion made Nov. 7 by member of faculty that subject should not be permitted for a time to play with football team in games against other teams; Nov. 16, statement made by subject that he had been doing a considerable amount of physical work; Nov. 18, played football at Suffield, Connecticut. Jan. 15, observed by one of us in gymnasium class as doing as well as average in class. Jan. 23, reported as not attending gymnasium classes owing to too small an amount of food for taking part in the gymnastic work. Feb. 1, 12 noon, "chinned bar" 12 times; had never tried it before. Same date, in afternoon, took part in arm-holding contest for 21 minutes of the 1-hour period; second man of Squad A to fall out.

GAR.

Greyson C. Gardner; born Aug. 16, 1895; home Cottage Grove, Indiana; age 22 years; height 171 cm.; nude weight 71.25 kilos. *Medical examination:* Oct. 2, 1917, negative. *Family history:* Resembles father, who is muscular but not fat; mother has grown stout in recent years; one uncle very stout. Two brothers and one sister, none of them stout. His sister (27 years old) has tuberculosis. No other cases of tuberculosis among relatives. *College course:* Physical. *Personal data:* Nov. 23 to 27, ill with cold, part of time in bed. Nov. 25, reported in morning that he was not feeling well; had not felt well at times for several days; made call in Holyoke, but was feverish, with chills, and obliged to lie down. Came back to Springfield in automobile; could hardly stand and almost fainted in getting out of car. Bowels unaffected; not constipated. Temperature about 9 p. m., 103° F., pulse 66; throat a little sore; feverish, with cold feet, backache, and soreness back of neck; physician called and prescribed for cold. Nov. 26, better; temperature at 11^h30^m a. m., 100° F., pulse 56. Nov. 27, 8^h15^m a. m., temperature 97.4° F., pulse 44. Dec. 11, diarrhea. Jan. 23, felt weak. *Physical activities:* According to personal estimate Sept. 27, about 27 hours a week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Nov. 15, played football on class team. Jan. 26, at 1 p. m., was seen to run downstairs. Gymnasium teacher at Springfield high school; six classes alternate days. Feb. 1, at 12 noon, "chinned bar" 22 times; probably equal to his best record. Same date, in afternoon, took part in arm-holding contest for full period of 1 hour.

GUL.

Otto A. Gullickson; born July 18, 1893; home Enderlin, North Dakota; age 24 years; height 166 cm.; nude weight 66.75 kilos. *Medical examination:* Nov. 21, 1917, negative. *Family history:* Mother fleshy (5 feet 6 inches,

weighs 195 pounds); two brothers and one sister thin; father very thin. No tuberculosis. *College course:* Physical. *Personal data:* Nov. 12, bowels affected. Nov. 26, pain in stomach. Dec. 11, diarrhea. Volunteered to give one pint of blood for blood transfusion at Springfield Hospital; Dec. 23, 100 c.c. blood taken; Dec. 29, 50 c.c.; Jan. 6, 90 c.c.; Jan. 17, 50 c.c.; total amount, 290 c.c. Report by physician; "Group III, Moss classification, negative Wassermann reaction." Feb. 5, sensation of fullness in stomach; unbuttoned vest. Feb. 5, vomited at night, expelling his dinner. At Boys' Club, Springfield, each night until 11 o'clock. *Physical activities:* According to personal estimate Sept. 27, about 33 hours a week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Nov. 15, played football on class team. Jan. 19, when fasting completely, "chinned" 12 or 13 times. Feb. 1 at 12 noon, "chinned bar" 14 times; 1913 record, 24 times. Same date, in afternoon, took part in arm-holding contest, continuing for whole period of 1 hour.

MON.

KIRK G. MONTAGUE; born Aug. 10, 1885; home Portland, Oregon; age 32 years; height 171 cm.; nude weight 68.75 kilos. *Medical examination:* Oct. 2, 1917, negative. *Family history:* Father and mother stout and tall, but not obese. Has three brothers who are fat; subject would resemble them were it not for exercise and work. *College course:* Physical. *Personal data:* Nov. 12, after uncontrolled Sunday had gas in stomach. Nov. 16, not so much vigor as used to have; thinks he is unable to study as well. Nov. 26, not feeling perfectly well. Dec. 14–16, using gargle for throat, which is a little sore; no temperature. Dec. 18, slight cold. *Physical activities:* According to personal estimate Sept. 27, about 35 hours a week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Nov. 14, played football on class team. Jan. 15, observed in gymnasium class by one of us and did as well as average of class. Feb. 1, at 12 noon, "chinned bar" 13 times; previous record unknown. Same date in afternoon, took part in arm-holding contest for full period of 1 hour.

MOY.

HENRY A. MOYER; born Oct. 27, 1894; home Rochester, New York; age 23 years; height 174 cm.; nude weight 63.50 kilos. *Medical examination:* Oct. 2, 1917, negative. *Family history:* Only child. Mother dead; no knowledge of how much she weighed. Paternal grandfather thin; father normal; subject resembles father. No tuberculosis. *College course:* Secretarial. *Personal data:* Nov. 12, some stomach trouble. Dec. 12, able to get on with little sleep, but feels weak. *Physical activities:* According to personal estimate Sept. 27, about 25 hours a week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Nov. 13, finished third out of 20 men in 5-mile cross-country run. Nov. 19, was met running towards Woods Hall, and remarked "lots of 'pep' this morning." Feb. 1, 12 noon, "chinned bar" 8 times; record previous summer, 12 times. Same day, in afternoon, took part in arm-holding contest for full period of 1 hour.

PEA.

ALLEN S. PEABODY; born Nov. 6, 1896; home Bradford, Massachusetts; age 21 years; height 169 cm.; weight 69.25 kilos. *Medical examination:* Oct. 2, 1917, negative. *Family history:* No obesity; no tuberculosis. Four brothers and one sister, all normal. *College course:* Physical. *Personal data:* Nov. 3, changed to heavy underwear on account of feeling cold; expected to

be able to change to lighter underwear when experiment is finished. Nov. 4, complained of being cold and low body temperature. Nov. 12, some bad feeling in stomach, but feels warm again. Nov. 21, slight cold. Nov. 26, slight stomach trouble. Dec. 13, feeling well, notwithstanding cold in head. *Physical activities:* According to personal estimate Sept. 27, about 25 hours a week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc.; captain cross-country team in college. Oct. 20, ran in 5-mile cross country race and won. Nov. 10, ran 5-mile cross-country race and came in second, 20 yards behind first man. Nov. 14, played football on class team. Nov. 17, ran 5-mile cross-country race and came in second. Nov. 28, took part in hare and hounds race; pedometer registered 6¾ miles; time 54 minutes; reported he felt fine and never better or as well as on that day. Observations before and after the race were as follows:

Before race (after breakfast): Lay down on bed, 9^h30^m a. m. Body temperature 98.6° F. Pulse-rate 49.0 per minute. Average respiration rate (for 12 minutes) 18.3 per minute. Alveolar carbon-dioxide tension 9^h45^m a. m. 47 to 50 mm. Body-weight without clothing 62.0 kilos.

After race: Body-weight without clothing, 11 a. m., 61.5 kilos; loss, 0.5 kilo. Lay down on bed 11^h05^m a. m. Body temperature 97.4° F. Pulse-rate 80 to 68 per minute. Average respiration rate (for 12 minutes) 23.3 per minute. Alveolar carbon-dioxide tension 11^h25^m a. m. (after 20 minutes on bed) 43 mm.

Dec. 4, observed in gymnasium class by one of us as doing as well as the average of class. Dec. 12, remarked that it was the first time in 2 months that he had been able to run up the three flights of stairs to the fourth floor two steps at a time; felt fine. Jan. 15, took part in wrestling match in gymnasium at a public demonstration of Japanese and American wrestling; the round between *Pea* and his opponent was a tie, there being no sign of inferiority in *Pea*. Feb. 1, at 12 noon, "chinned bar" 15 times; previous best record 18 times two years before. Same date, in afternoon, took part in arm-holding contest, continuing for full period of 1 hour.

PEC.

R. Wallace Peckham; born Sept. 12, 1873; home Springfield, Massachusetts; age 44 years; height 170 cm.; nude weight 64.25 kilos. *Medical examination:* Oct. 2, 1917, negative other than moderate varicocele. *Family history:* No obesity; no tuberculosis. *College course:* Secretarial. *Personal data:* Captain of Squad A. Married. November 4, complained of being cold and low body temperature. Dec. 10, uncomfortable feeling in stomach as a result of eating too much. Jan. 23, complained of feeling weak. *Physical activities:* According to personal estimate Sept. 27, about 25 hours a week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Nov. 7, a large amount of exercise about this time to reduce weight, including swimming 1 mile, running 4 or 5 miles, playing soccer ball and handball. Nov. 15, played football on class team; discharged during second half of game on account of poor playing. Feb. 1, 12 noon, "chinned bar" 5 times; previous best record probably 5 to 10 times. Same date, in afternoon, took part in arm-holding contest, continuing for 56½ minutes of 1-hour period; fourth man of Squad A to fall out.

SPE.

Wesley G. Spencer; born July 16, 1898; home Andover, Massachusetts; age 19 years; height 171 cm.; weight 63.50 kilos. *Medical examination:* Oct. 2, 1917, negative. *Family history:* No obesity. One aunt, father's

sister, considered a consumptive, but appears to have recovered; now 53 years old and comfortable, but cannot live on sea coast. Father refused life insurance by Connecticut Mutual Life Insurance Co. a number of years ago because underweight and suspected of incipient tuberculosis; received a policy from New York Life Insurance Co. and later from another insurance company in Philadelphia. Dr. Goodall found in the tip of one of the lungs of *Spe* a spot that looked as if there had been a process there, but otherwise nothing significant. *College course:* Physical. *Personal data:* Oct. 26, *Spe's* pulse took an unusually long time to return to normal after bicycle riding; he was feverish; Oct. 27, 1917, fever night before and pulse unsettled; believed he had the grippe; face somewhat flushed and bad odor to breath; Oct. 28, 1917, reported himself all right; Nov. 16, toothache; slight infection of gums over wisdom tooth; gum lanced; toothache promptly relieved; Nov. 18 and 19, felt fine; Nov. 26, felt all right; Dec. 10 and 11, felt fine; Dec. 12, felt weak, throat a little sore, temperature at 5^h45^m a. m., 99.6° F.; excused from respiration experiment; stayed in bed, headache, appetite poor; Dec. 13, felt better, temperature 100.5° F.; temperature taken later by physician and reported as 102° F. (pulse 120); at 2 p. m. physician suspected typhoid fever; at 6^h30^m p. m. temperature 102.5° F., pulse 102; Dec. 14, after consultation of two doctors case pronounced probably typhoid; Dec. 15, went home to Andover; case pronounced typhoid fever by Andover physician; returned to college Apr. 2, 1918. *Physical activities:* According to personal estimate Sept. 27, 1917, about 28 hours a week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Nov. 14, played football on class team.

TOM.

LESLIE J. TOMPKINS; born July 21, 1892; home Yonkers, New York; age 25 years; height 176 cm.; nude weight 59.50 kilos. *Medical examination:* Oct. 2, 1917, negative. *Family history:* All relatives either normal or thin on both sides of family; only brother thin. Mother died of pulmonary hemorrhage due to tuberculosis. *College course:* Secretarial. *Personal data:* Nov. 16, said he had no ambition and could not take more exercise than he was then taking; thought he needed more sleep. Nov. 25, took cascara. Dec. 3, had had diarrhea, probably as a result of eating greens two or three days before; still had pain and loose bowels. Dec. 6, copious stools. Dec. 12, no bowel movements since the first part of the week, 2 or 3 days before. Dec. 16, bowel trouble due to something eaten; other students eating at Woods Hall were also affected. At 11 a. m., temperature 96.8° F.; pulse 44. Dec. 17, still some diarrhea. During the Christmas holidays hemorrhoids developed, forming a blood clot, necessitating an operation. Operation for blood clot Dec. 24 and for hemorrhoids Dec. 27; ether both times; spent over one week in hospital. Left hospital Jan. 2 and returned to college Jan. 11, feeling somewhat weak and considerable discomfort from operation. Jan. 13, much difficulty in moving bowels; rectum irritated and skin about anus raw. Jan. 15, throat dry, headache, and so ill that he went to bed. Jan. 17, passed some blood at end of bowel movement. Jan. 23, felt weak. Jan. 24, considerable weakness and able to exercise but little. Jan. 25, delegate to Y. M. C. A. convention in Boston. Feb. 5, went to turkey dinner at *Pec's*, ate more than *Vea*. Sick Feb. 6. Managed college store during winter. *Physical activities:* According to personal estimate Sept. 27, about 25 hours spent each week in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Feb. 1, 12 noon, "chinned bar" 7 times; best record 12 times one year before. Same date, in afternoon, took part in arm-holding contest, continuing 18½ minutes of 1-hour period; first man of Squad A to fall out.

VEA.

RONALD T. VEAL; born Sept. 6, 1895; home Michigan City, Indiana; age 22 years; height 175 cm.; nude weight 65.75 kilos. *Medical examination:* Oct. 2, 1917, negative. *Family history:* Most of mother's family fleshy; father's family thin; subject resembles father. *College course:* Secretarial. *Personal data:* Nov. 7, had cold, sore throat, and felt ill. Dec. 10, felt chilly at supper time, but no sore throat. Dec. 12, was nervous; hardly able to shave. Jan. 31, counted pulse sitting in class at 10^h15^m a. m., 32 per minute; later, lying down for about 4 minutes in his room, at 11^h30^m a. m., 28 per minute. *Physical activities:* According to a personal estimate on Sept. 27, about 21 hours a week spent in physical exercise, such as walking, playing tennis, football, gymnasium work, etc. Feb. 1, at 12 noon, "chinned bar" 5 times; best record 15 times three years before. Same date, in afternoon, took part in arm-holding contest, continuing to end of 1-hour period.

SQUAD B.

FIS.

EDWARD M. FISHER; born Aug. 10, 1891; home Reading, Pennsylvania; age 26 years; height 177 cm.; nude weight 76.0 kilos. *Family history:* Father 5 feet 10 inches and weighs 230 pounds. Mother normal, has three sisters, all healthy, not stout, also two brothers normal. No tuberculosis. *College course:* Physical. *Personal data:* Operation for hernia; in hospital Dec. 4–19, inclusive.

HAR.

VICTOR H. HARTSHORN; born Mar. 9, 1898; home Washington, D. C.; age 20 years; height 175 cm.; nude weight 63.0 kilos. *Family history:* Mother and father both rheumatic. *College course:* Physical. *Personal data:* No record.

HOW.

KARL Z. HOWLAND; born Mar. 12, 1899; home Phillips, Maine; age 19 years; height 179 cm.; nude weight 70.0 kilos. *Family history:* Father and mother died of tuberculosis of lungs; only child. *College course:* Physical. *Personal data:* No record.

HAM.

ROBERT L. HAMMOND; born Oct. 1, 1897; home Derby, Connecticut; age 20 years; height 184 cm.; nude weight 75.0 kilos. *Family history:* Negative. Has two brothers who are thin; one sister healthy. *College course:* Physical. *Personal data:* Can eat no fruit or jelly, as he says he can not keep them down; was not asked to eat them.

KIM.

HAROLD L. KIMBALL; born Feb. 11, 1893; home Waltham, Massachusetts; age 25 years; height 176 cm.; nude weight 61.9 kilos. *Family history:* No obesity or tuberculosis. One brother, thin. *College course:* Secretarial. *Personal data:* Jan. 5, 1918, served as subject in Boston first time in place of *Lon.* Jan. 21, said "It is a long way up here (4th floor of Laboratory); I feel a little weak."

LON.

ROBERT H. LONG; born March 14, 1896; home Brooklyn, New York; age 22 years; height 179 cm.; nude weight 66.8 kilos. *Family history:* Mother "rather stout"; dead. Father normal. Only child. No tuberculosis in

family. *College course:* Physical. *Personal data:* Jan. 5, 1918, ill and not present in Boston; place taken by *Kim.* Jan. 15, observed by one of us in gymnasium drill and noted as doing as well as average of class.

SCH.

JOHN SCHRACK; born Oct. 3, 1888; home Reading, Pennsylvania; age 29 years; height 166 cm.; nude weight 68.6 kilos. *Family history:* Family all thin, this subject being the heaviest one in the family. Four brothers and one sister, normal. No tuberculosis. *College course:* Physical. *Personal data:* Jan. 5, 1918, served as subject in Boston first time, taking place of *Mac.* Jan. 21, somewhat tired. *Physical activities:* Jan. 22, 1918, reported as not losing much weight, because he is less active.

LIV.

ALFRED LIVINGSTONE; born May 23, 1899; home Paterson, New Jersey; age 18 years; height 161 cm.; nude weight 60.5 kilos. *Family history:* All members of his family are short, but of average weight. Three brothers, all short. No tuberculosis. *College course:* Physical. *Personal data:* No record. *Physical activities:* Jan. 15, 1918, took part in public demonstration of Japanese and American wrestling in gymnasium. Like *Pea.*, the round with his opponent was a tie. The time was short, but no inferiority was apparent with *Liv.* Jan. 24, janitor remarked that the boys were not as they used to be, for usually he had only to ask for help and he had all he wanted. He referred to *Wil* and *Liv* in particular, who said they could not work, as they did not feel like it.

SNE.

CHESTER D. SNELL; born Nov. 24, 1895; home Canajoharie, New York; age 22 years; height 175 cm.; nude weight 72.3 kilos. *Family history:* Negative. *College course:* Secretarial. *Personal data:* Operation for correction of deviated septum from nasal partition, November 10, 1917. Did not go to bed, but felt weak for first 7 days. Afterwards only discomfort was due to rubber splint in nose, which was worn 4 weeks.

THO.

GEORGE H. THOMPSON; born Feb. 18, 1894; home Poughkeepsie, New York; age 24 years; height 179 cm.; nude weight 62.0 kilos. *Family history:* Negative. *College course:* Secretarial. *Personal data:* Captain of Squad B.

VAN.

FLOYD M. VAN WAGNER; born Mar. 27, 1894; home Hyde Park, New York; age 24 years; height 179 cm.; nude weight 67.3 kilos. *Family history:* All stout in father's family. Three brothers and one sister normal. Subject the heaviest in the family. No tuberculosis. *College course:* Physical. *Personal data:* No record.

WIL.

ELTON L. WILLIAMS; born Oct. 31, 1898; home Chelsea, Massachusetts; age 19 years; height 164 cm.; nude weight 58.5 kilos. *Family history:* Father weighed 250 pounds 10 years ago, weighed 200 pounds 5 years ago, weighs now 189 pounds. An aunt and a cousin died of tuberculosis. *College course:* Physical. *Personal data:* Jan. 24, 1918, see remark made by janitor in data for *Liv.*

The following subjects, as explained in their histories, served as members of Squad B for only a part of the time, and not during the weeks of diet reduction with this squad:

McM.

Harry T. McMichael; born Sept. 18, 1897; home Belleview, Ohio; age 20 years; height 169 cm.; nude weight 67.6 kilos. *College course:* Secretarial. *Personal data:* Succeeded *Kon*, who was transferred to Squad A. Came to Boston with Squad B Nov. 3–4, Nov. 17–18, Dec. 15–16, and Jan. 5–6. Jan. 7, was ill in the forenoon, but at 7^h30^m p. m. felt better; temperature 101.3° F. Excused from further service on squad, as his parents refused to sign a permit for him to join in the diet reduction, and he had suffered from a stomach trouble for the previous 10 days. Succeeded by *Kim*.

LEO.

Clinton S. Leonard; born Apr. 27, 1897; home East Taunton, Massachusetts; age 21 years; height 183 cm.; weight 77.5 kilos. *College course:* Secretarial. *Personal data:* Substituted for *Fis* (who was ill) on the visit of Squad B to Boston, Dec. 15–16.

MAC.

Angus J. Macdonald; born Sept. 19, 1891; home Cambridge, Massachusetts; age 26 years; height 174 cm.; nude weight 66.5 kilos. *College course:* Physical. *Personal data:* Served in Squad B on visits to Boston Oct. 6–7, Nov. 3–4, Nov. 17–18, and Dec. 15–16; later called to the Naval Reserves and succeeded by *Sch*.

PROGRAM OF RESEARCH.

The research began with the fundamental question of the selection of subjects, the various requirements and degree of personal integrity demanded of the men limiting our field of selection greatly. Pending the actual selection of subjects, a large amount of preliminary work was done in getting together apparatus for studying the respiratory exchange and gas analysis and planning for the transportation of a considerable amount of material to Springfield. As previously stated, the selection of men was based in part upon physical qualifications and intellectual ability, and none of the men in Squad A were accepted until Dr. Chapin had been convinced that they were in good physical condition, according to clinical standards. This squad was placed at a special table and allowed to eat *ad libitum* for several days, so that the normal food consumption of the men prior to restriction might be determined. In this preliminary period the food was carefully aliquoted, sampled, and prepared for analysis. The following instructions were given Squad A and in somewhat revised form to Squad B:

The highly scientific character of this research and its magnitude are such as to demand from all connected with the work, either as subjects or as assistants and collaborators, an honest, faithful and accurate service ever maintained above reproach.

1. The subject must be in good health and confident of continued good physical condition under usual conditions of living.

2. He will sign an affidavit of his willingness to subscribe to all the requirements of the research.

3. He will promise uninterrupted service and cooperation during the entire period of observation and will not seek to be released from his responsibilities as a subject until the completion of the research unless compelled to do so by

major causes, such causes to be declared justifiable by the squad physician (a Springfield physician) or by a committee of the faculty. This period is to begin on Wednesday, Sept. 26, 1917, and end by Christmas, 1917.

4. Provision is to be made for the possibility of continuing the observations from 2 to 3 weeks longer if necessary. As this is likely to interfere seriously with the plans of some subjects during the Christmas vacation, it is possible that some way may be provided to meet the requirements of the research and still allow subjects to absent themselves during the usual holiday period.

5. The subjects will conform to the usual modes of living as regards work, exercise, diet (except as restricted) and sleep. No radical change in the ordinary daily life of the subject is permitted.

6. The subject will submit to a reduction in the daily food allowance sufficient to induce a loss of 10 per cent or more of body-weight in as short a time as possible, and also to maintain this acquired reduction in weight until the end of the test period.

7. The food will be served at a table reserved for the squad of subjects in Woods Hall dining room and will consist of the regular bill of fare for all students of the college.

8. It is desired that all portions of the food served be eaten completely. If not, the person in charge of the serving must be notified and will make a record of the food not eaten and, if necessary, collect it for analysis. It is supposed that when the ration is reduced the subjects will have no difficulty in eating the entire ration served.

9. The subject will not eat or drink anything whatsoever outside of the regular three meals served under supervision.

10. Water only in reasonable quantity is allowed at any time.

11. The subject must clearly understand that under the conditions of the research, the partaking of ice cream, fruit, peanuts, popcorn, etc., as well as sodas or drinks of any kind, unless intentionally served as a part of the regular allowance, is absolutely prohibited. The moderate chewing of gum is not prohibited.

12. It must, however, be understood that any breaking of this most important rule should be promptly reported, as by so doing the seriousness of the offense can be in part minimized.

13. *Collection of the urine:* (*a*) *All* urine voided will be continuously collected for exact periods of 24 hours each in properly labeled bottles which will be provided for the purpose. (*b*) Each 24-hour collection will be completed daily at $5^{h}30^{m}$ a. m. and placed at the disposal of the collector in charge at the place indicated for this. (*c*) No urine should be lost. Accidental losses must be prevented. If any occur they must be carefully noted and the quantity lost reported as accurately as possible the same day. (*d*) The loss of urine during defecation will be prevented by the simultaneous use of a urine-collecting bottle. (*e*) If urination is to occur away from the college premises the subject must take with him a bottle to receive the urine passed, which is to be added to the day's collection. (*f*) The collection of urine at the time the squad goes to Boston will not be interrupted until Sunday morning. Provision for this must be made as needed. The collection of urine on the Sundays in Boston will be omitted according to instructions given elsewhere.

14. *Collection of feces during weekly digestion period:* (*a*) Each Monday morning at breakfast with the first mouthfuls of food eaten, two or three gelatin capsules containing charcoal or carmine are to be swallowed. They will likewise be given with the first meal on Thursday morning. (*b*) Collect all the stools from Monday until the collector in charge will have notified

you that the charcoal given on Thursday morning has made its appearance in the stools. Under ordinary circumstances this will occur on Friday or perhaps not until Saturday.

15. *Trips to Boston:* (*a*) On Saturday afternoon, Sept. 29, and every two weeks hereafter, the squad will be taken to Boston. (*b*) On arriving a regulation supper will be served at a restaurant and the squad then conducted to the Nutrition Laboratory. (*c*) The evening will be spent in making various tests and taking measurements on the subjects. (*d*) The squad will retire and sleep in a large chamber constructed for the purpose of estimating the basal metabolism of its occupants. (*e*) Breakfast will be served at the laboratory on Sunday morning, after which the squad will be free to spend the day as it desires with the understanding that: (1) A low ration diet will be adhered to at noon and evening. (2) No urine need be collected from 5^h30^m a. m. Sunday until 5^h30^m a. m. Monday. This period, in which urine is *not* to be collected, ends with and includes the emptying of the bladder at exactly 5^h30^m a. m. each Monday. The first passage of urine to be again collected will be the first urination following that of 5^h30^m a. m. which is discarded only on each Monday morning.

16. *Respiration tests:* Subjects will be numbered from 1 to 12. Nine subjects will be examined daily according to a schedule to be made later. These tests will be made before breakfast every day except on the Sundays when the squad is in Boston. The time for these tests will be set so as not to interfere with the regular class work of the students.

In accordance with this agreement no food other than that served at table could be eaten. The men were particularly cautioned against the consumption of candies, peanuts, ices, etc., to which they were more or less accustomed. The following measurements were made for the most part with Squad A and also with Squad B during diet restriction:

Urine and feces.—Twenty-four hour amounts of urine were collected and the specific gravity and total nitrogen determined. To note the possibility of digestive disturbance, feces were collected at various intervals throughout the test. The nitrogen and total energy of the feces were determined, these supplying a measure of the digestibility of protein and total calories.

Body-weight.—As the foremost index of body condition and state of nutrition, body-weights were recorded under standard conditions, that is, with the subject nude, in the post-absorptive state, with an empty bladder, and without the previous drinking of water. Each weight was checked, not only by a member of the squad, but by a representative of the Nutrition Laboratory, and the date and time recorded.

Body-surface measurements.—To serve the dual purpose of giving a record of the changes in body-surface and a general index of the physical state, a series of body-surface measurements was made according to the method of Du Bois. These measurements were supplemented by anatomical photographs taken at frequent intervals throughout the test.

Records of activity.—No one factor plays a greater rôle in the consumption of energy than muscular activity. As the simplest index,

crude though it may be, the pedometer was used. Furthermore, the men were frequently questioned as to their extraneous physical activities other than normal. During certain periods a schedule of the actual activities during a period of one week was obtained.

Pulse measurements.—The pulse is the best general index of the metabolic level; hence every effort was made to secure pulse measurements as frequently as possible, but under controlled and comparable conditions. These included observations with the subject lying quietly in the post-absorptive condition, sitting during meals, standing and in the post-absorptive condition, lying quietly before and after riding on a bicycle ergometer, standing before and after walking experiments, and during walking. Wrist counts were supplemented by standard electrocardiograms and electrocardiograms during exertion.

Clinical examinations.—Clinical examinations of Squad A and of Squad B during diet restriction were carefully made by Dr. Goodall. These included examinations of the heart, lungs, reflexes, glands, and blood pressure.

Blood examination.—Somewhat late in the test arrangements were made, through the kindness of Dr. George R. Minot of Boston, for a series of careful blood examinations. We were so fortunate as to secure the cooperation of Miss Anna L. Gibson and her associate, Miss M. B. Conover, who made the blood examinations on nearly every visit of the squads to Boston after December 19.

Body temperature.—Each morning prior to the gaseous metabolism experiments in Springfield, the temperature was taken in the mouth with a clinical thermometer, simply to show the absence of fever. For true physiological measurements we relied upon the temperature taken in the rectum at the end of the night experiments in the large chamber in Boston. To give a possible suggestion as to changes in skin temperature, electrical measurements of surface temperature were taken during the latter part of the test.

Gaseous metabolism.—The gaseous metabolism was measured under four different conditions: (1) With the subjects lying quietly and in the post-absorptive condition, by means of the respiratory-valve apparatus and the portable respiration apparatus; (2) with the subjects lying asleep after a light supper, in a night experiment with the group respiration chamber; (3) with the subjects in the post-absorptive condition and in the standing position; and (4) with the subject walking on the treadmill in the treadmill chamber. The first two measurements gave an indication of the basal metabolism of the subjects, the third provided a base line for the metabolism during walking, and the fourth supplied evidence of the energy requirements for the ordinary activities of the day. The fourth series of observations also gave information as to the effect of a reduced diet upon the efficiency of the men in ordinary physical activity.

Psycho-physiological measurements.—An extended series of psycho-physiological measurements was made by approved methods in both group and individual tests whenever the subjects visited Boston. Full details are given of the various tests in later sections.

WEEK-END PROGRAM.

To illustrate the personal demands made upon the subjects as a result of these observations, a typical week-end program for Squad A is given. Beginning early Friday morning at Springfield, the activities of the squad are shown until the conclusion of the tests on Sunday in Boston.

Friday:

5^h30^m a. m. Nine men ready for respiration experiments; 7 men portable respiration apparatus; 2 men respiratory-valve apparatus. Routine of experiments: Bladder emptied; weighed (stripped); lay on couch for preliminary period; mouth temperature taken; two periods (10 to 15 minutes each) on respiration apparatus; pulse and respiration rates taken during experiment; alveolar air determinations made for 2 men on respiratory-valve apparatus.

6^h45^m a. m. Breakfast; pedometer readings recorded.

9^h30^m to 11^h30^m a. m. Bicycle ergometer experiments with Professor Johnson; 5-minute periods; subjects, *Bro, Gul, Gar.*

12^h10^m p. m. Dinner; pulse-rate counted at wrist by subject (sitting).

1^h30^m to 4^h30^m p. m. Bicycle ergometer experiments with Professor Johnson; subjects, *Pec, Vea, Can, Moy, Spe, Mon, Tom, Kon, Pea.*

6 p. m. Supper; pulse-rate counted at wrist by subject (sitting).

Saturday:

5^h30^m a. m. Nine men ready for respiration experiments; regular routine followed.

7^h30^m a. m. Breakfast.

9^h10^m a. m. Train Springfield to Boston.

11^h36^m a. m. Squad arrived in Boston.

12 (noon). Standard dinner at restaurant.

5 p. m. Standard supper at restaurant.

5^h45^m p. m. Squad arrived at Nutrition Laboratory.

6 to 7 p. m. Group psychological tests in library at Laboratory. For order of tests see section on technique (page 139) and program of research (page 149). Pulse-rates (sitting) during psychological tests; skin temperature measurements at end of psychological tests.

7 to 10^h30^m p. m. Individual psychological measurements in psychological laboratory (60 to 70 minute period); measurements given to 4 men simultaneously. When not occupied with psychological tests, the men were given the following: Clinical examination by Dr. Goodall; blood tests by Miss Gibson; Du Bois body-surface measurements; profile photographs; 5-minute practice in walking on treadmill.

10^h00^m to 10^h30^m p. m. Men went to bed in the group respiration chamber as soon as all had finished the tests previously mentioned.

10^h45^m p. m. Men all in bed, cover of group chamber closed; preliminary period of experiment began.

11^h15^m p. m. Respiration experiment proper began; periods approximately 30 minutes long throughout the night.

Sunday:

5 a. m. Respiration experiment ended.

5^h50^m a. m. Cover taken off group chamber.

6 a. m. Routine for each subject as follows: Rectal temperature and pulse-rate determined by observer with subject lying; subject then rose, emptied bladder, was weighed nude, dressed, and received standard laboratory breakfast.

6^h30^m to 9 a. m. Individual psychological measurements given to subjects, three men at a time, in 25-minute periods. Men then free for the rest of the day.

On Jan. 6 and 28 for Squad B and Feb. 3 for Squad A, the program for Sunday morning was changed to include experiments on the treadmill and portable respiration apparatus. On these dates the Sunday morning program was as follows:

3^h50^m a. m. Respiration experiment in group chamber ended.

4 a. m. Cover taken off group chamber.

4^h15^m a. m. Rectal temperature and pulse-rate measured as before, also bladder emptied; first man weighed nude on second floor of Laboratory; he then dressed, was given a glass of water to drink, and went to third floor of Laboratory for experiments. Same routine followed for other men in turn.

4^h25^m a. m. to 1 p. m. Standing experiments with portable respiration apparatus, and walking experiments with treadmill apparatus; men called in turn at intervals of 20 to 30 minutes.

Routine of experiment with portable respiration apparatus: Two experimental periods, each 12 to 15 minutes long; pulse and respiration rates taken during experiment; blood pressure taken at end of experiment.

Routine of treadmill experiment:[1] Electrodes adjusted and pulse-rate taken in hall outside of treadmill room; pulse-rate, sitting in treadmill room; pulse-rate, standing on treadmill; pulse-rate, transition standing to walking. *Preliminary period:* 4 minutes walking on treadmill, with cover off of chamber 2½ minutes. *Main period:* Walking on treadmill, with cover on chamber, 20 minutes; electrocardiograms taken and approximate measurement of respiration rate made during 6th, 12th, and 24th minutes of walking. Visual counts of deflections of galvanometer each minute made during preliminary period and main period of experiment; total distance traveled recorded; total number of steps recorded. *After experiment:* Pulse-rate taken, transition walking to standing; successive blood-pressure measurements immediately at end of walking for period of 2 minutes; subject weighed with electrodes and dressed as on mill; blood pressure and radial pulse, sitting, for 10 minutes; strength of grip, but no other psychological measurements. Men dismissed as each finished the last test.

CHRONOLOGICAL HISTORY OF LOW-DIET RESEARCH.

To give a general idea of the research and the sequence of events, a chronological history, for both Squads A and B, is included here for the period from September 22, 1917, to May 22, 1918, inclusive.

September 22. Shipment of apparatus and general supplies from Boston to Springfield.

[1] Transition pulse-rate, standing to walking, and walking to standing, visual counts of the galvanometer, and blood-pressure measurements immediately at the end of walking not taken with Squad B on January 6.

September 24. General call for volunteers.

September 25. Unpacking and installation of apparatus.

September 27, Squad A. First experiments in Springfield with respiratory-valve apparatus and portable respiration apparatus and first records of pulse-rate; first collection of urine.

September 29, Squad A. Came to Boston (*Kon* excepted). Came to Laboratory immediately after prescribed evening meal and took psychological tests for first time in following order:

Group tests in library:

Accuracy in tracing between irregular parallel lines.

Memory span for 4-letter English words.

Addition of one-place numbers for a period of 10 minutes.

Discrimination for specified number groups on a printed page.

Discrimination for the pitch of tone.

Individual tests in psychological laboratory and adjoining rooms:

Sensory threshold for electric shock.

Latency, amplitude, and refractory period of the patellar reflex.

Speed of the finger movements.

Efficiency in traversing a right-angle maze.

Efficiency in performing certain clerical tasks.

In addition to psychological measurements, other measurements were: First Du Bois surface measurements; first profile photographs; first experiment in group respiration chamber.

September 30, Squad A. In Boston at Laboratory part of morning. First record of body-weight.

October 1 to 3, inclusive, Squad A. Normal diet at training table; food portions weighed, sampled, and samples analyzed. First digestion period for collection of feces. (*Pec* not included; he was always irregular in these periods.)

October 2, Squad A. Physical examination, Dr. Chapin (*Can, Gul,* and *Kon* excepted).

October 4, Squad A. First reduction in diet.

October 6, Squad A. Pedometers used from this date to end of experiment. First use of bran in diet.

October 6, Squad B. Came to Boston. At Laboratory immediately after prescribed evening meal and took psychological experiments as outlined for Squad A on September 29. *Kon* and *Mac* included in these measurements, but *McM, Kim,* and *Sch* not included. First experiment in group respiration chamber.

October 7, Squad B. First record of body-weight (*McM, Kim,* and *Sch* excepted).

October 8–11, inclusive, Squad A. Second digestion period for collection of feces.

October 9, Squad A. Affidavit signed.

October 10, Squad A. Began using margarine instead of butter for some of the meals.

October 13, Squad A. Came to Boston; supper at restaurant. At Laboratory after evening meal; second series psychological tests. Added to tests:

Sensory threshold for visual efficiency (acuity).

Reaction time for speaking 4-letter words.

Continuous discrimination and reaction in finding serial numbers.

First clinical examination, Dr. Goodall; second experiment in group respiration chamber.

October 14, Squad A. In Boston; at Laboratory part of morning. Meals uncontrolled on this date, except for breakfast at Laboratory.

October 16, Squad A. Topped milk, *i. e.*, part of cream removed, used on this date and subsequently; whole milk used previous to this date.

October 17–20, inclusive, Squad A. Third digestion period for collection of feces.

October 19, Squad A. First bicycle ergometer experiments made by Professor Johnson; made on Mondays and Fridays throughout research with Squad A.

October 24, Squad A. Last day *Fre* ate at training table.

October 24, Squad B. First bicycle ergometer experiments with Professor Johnson; made on Wednesdays with Squad B throughout research.

October 27, Squad A. Came to Boston; supper at restaurant. Psychological tests previously described, also strength of grip. *Kon* served in place of *Fre*. Second clinical examination, Dr. Goodall (first for *Kon*); second profile photographs (first for *Kon*); first Du Bois body-surface measurements for *Kon*. Third experiment in group respiration chamber (11 men only, *i. e.*, without *Kon*).

October 28, Squad A. In Boston; at Laboratory part of morning. Meals uncontrolled on this date, except for breakfast at Laboratory. First Sunday morning program for psychological measurements; individual measurements as follows:

Changes in pulse-rate occasioned by short periods of exertion.
Reaction time for turning the eye to a new point of regard.
Speed of the eye movement.
Two finger movement records, like those taken in evening.
Strength of grip.

October 30, Squad A. Kon at training table for first time.

Oct. 31 to Nov. 3, inclusive, Squad A. Fourth digestion period for collection of feces.

November 3, Squad A. First use of currant jelly to replace more or less butter in diet.

November 3, Squad B. Came to Boston. Evening psychological tests. *McM* served as subject in place of *Kon*, transferred to Squad A. Second experiment in group respiration chamber.

November 4, Squad B. In Boston; at Laboratory part of morning. First Sunday morning program of psychological measurements. (See Oct. 28 for outline.)

November 10, Squad A. Came to Boston; dinner and supper at restaurant (*Pea* had dinner in Springfield). Regular evening psychological tests. Third clinical examination, Dr. Goodall. Individual 5-minute practice walking on treadmill in preparation for subsequent walking experiments. Questioned in evening regarding introspection on diet, hunger pains, physical endurance, etc. Fourth experiment in group respiration chamber.

November 11, Squad A. In Boston; at Laboratory part of morning. First rectal temperature measurements, with subject lying in group respiration chamber after night experiment. Regular morning program psychological measurements. Meals uncontrolled on this day except for breakfast at Laboratory.

Nov. 12 to 17, inclusive, Squad A. Fifth digestion period for collection of feces.

November 13, Squad A. Use of bran muffins begun.

November 17, Squad B. Came to Boston; supper at restaurant. Regular evening psychological tests. Individual 5-minute practice walking on treadmill. Third experiment in group respiration chamber.

November 18, Squad B. In Boston; at Laboratory part of morning. First rectal temperature measurements, with subject lying in group respira-

tion chamber after night experiment. Regular morning psychological experiments.

November 21, Squad A. Can and *Gul* examined by Dr. Chapin; *Kon* never examined by Dr. Chapin.

November 24, Squad A. Came to Boston; dinner and supper at restaurant. Went to theatre in afternoon. Regular evening program of psychological measurements. Individual 5-minute practice walking on treadmill. Fourth clinical examination, Dr. Goodall; third profile photographs; second Du Bois surface measurements (*Moy* and *Spe* not included). Fifth experiment in group respiration chamber.

November 25, Squad A. In Boston; at Laboratory part of morning. Regular morning program of psychological measurements. Second Du Bois body-surface measurements of *Moy* and *Spe*. First pulse measurements with subjects lying in group respiration chamber. Meals uncontrolled on this date except for breakfast at Laboratory.

Nov. 29 to Dec. 2, inclusive, Squads A and B. Thanksgiving recess. Urine collected practically every day by *Bro, Gul, Moy, Pec*, and *Vea*.

Dec. 7 to 13, inclusive. Occupational records kept by *Can* and *Moy* of *Squad A, Tho* and *Sne* of *Squad B*, and 9 other man not in the squads.

December 8, Squad A. Agreement signed to continue on experiment to February 2. Approved by Professor Berry. Came to Boston; dinner and supper at restaurant. Regular evening psychological program. Began to take pulse counts in connection with psychological tests. Individual 5-minute practice walking on treadmill. Fifth clinical examination, Dr. Goodall. Sixth experiment in group respiration chamber.

December 9, Squad A. In Boston; at Laboratory part of morning. Morning psychological program, except for omission of measurements of pulse-rate after short periods of exertion (string galvanometer out of order). Meals uncontrolled on this day, except for breakfast at Laboratory.

Dec. 10 to 14, inclusive, Squad A. Sixth digestion period for collection of feces.

December 12, Squad A. Agreement signed as to method of designation of subjects by full name in published report of research.

December 13, Squad A. Last day *Spe* ate at training table.

December 13, Squad B. Pedometers given men and records of walking obtained from this date to end of experiment.

December 15, Squad B. Came to Boston; supper at restaurant. Regular evening psychological program. Began to take pulse counts in connection with the psychological tests. *Fis* ill and not present; substitute, *Leo*, in all but psychological measurements. Individual 5-minute practice in walking on treadmill. Fourth experiment in group respiration chamber.

December 16, Squad B. In Boston; at Laboratory part of morning. First records of pulse-rate, with subject in lying position, after night experiment in group respiration chamber. Regular morning psychological measurements.

December 19, Squad A. Came to Boston; dinner and supper at restaurant. *Tom* had dinner in Springfield. Regular evening psychological program. Individual 5-minute practice walking on treadmill. First blood tests, Miss Gibson; sixth clinical examination, Dr. Goodall. Seventh experiment in group respiration chamber.

December 20, Squad A. In Boston; at Laboratory part of morning. Electrocardiograms taken on three men while they were in bed in the group

respiration chamber; others taken on some of the men while they were in reclining position in the psychological laboratory.

Dec. 20, 1917, to Jan. 6, 1918, inclusive. Christmas recess. *Squad A.* Urine collected daily by *Gul;* except on December 22–30 and December 31—January 1 by *Pec.*

January 5, Squad B. Came to Boston; supper at restaurant. Regular evening psychological measurements. *McM* had had trouble with stomach previous 10 days; *Lon* ill, substitute, *Kim; Mac* called to Naval Reserves and *Sch* took his place. Regular psychological measurements on two new subjects, *Kim* and *Sch.* First clinical examination, Dr. Goodall; first blood examination, Miss Gibson; first Du Bois body-surface measurements; first profile photographs. Fifth experiment in group respiration chamber.

January 6, Squad B. In Boston; at Laboratory part of morning. First body-weights for *Kim* and *Sch.* First standing experiments with portable respiration apparatus and first pulse records standing. First treadmill walking experiments. No psychological measurements in morning, only strength of grip. Standing and treadmill experiments made serially, the routine for the first subject, which was typical of the others, being as follows: First subject called at about 4^h00^m a. m.; when weighed and dressed, he served two periods as subject for standing experiment, with pulse records during standing; at 5 o'clock he was ready for the 24-minute treadmill experiment; pulse record made 5 minutes after walking experiment ended.

January 7, Squad B. First urine collections by all but *How* and *Lon.* *Kim* now serving in place of *McM.*

January 7, Squad A. Can, Gar, Gul, Mon, Pea, Pec, and *Vea* returned from Christmas recess; at table for all three meals on this day. *Moy* at dinner and supper, but breakfasted elsewhere.

January 8, Squad A. Bro returned and at training table.

January 8. Squad B. First urine collections by *How* and *Lon.* First day of controlled, reduced diet.

January 9, Squad B. Affidavit signed

January 11, Squad A. Kon and *Tom* returned; ate only supper at training table. *Spe* did not return to the squad.

Jan. 11 to Feb. 2, Squad A. Exercise records kept during this period.

Jan. 11 to Feb. 3, Exercise records kept by an uncontrolled squad of fellow students.

January 11 to 28, Squad B. Exercise records during this period.

January 12, Squad A. Came to Boston; dinner and supper at restaurant. *Tom* had dinner in Springfield. Regular evening psychological program. Individual 5-minute practice on treadmill. Seventh clinical examination, Dr. Goodall. Second blood examination, Miss Gibson. Eighth experiment in group respiration chamber.

January 13, Squad A. In Boston; at Laboratory part of morning. Regular morning psychological program. Meals uncontrolled except breakfast at Laboratory. This was the last Sunday of uncontrolled meals. Excess eating on this date and consequent gain in weight led to subsequent sharp reduction in diet for a few days for *Kon, Bro,* and *Gar.*

January 13, Squad B. Came to Boston; lunch on train; supper at restaurant. Regular evening psychological program. *Kim* serving in place of *McM* and *Sch* in place of *Mac.* Individual 5-minute practice walking on treadmill. Second blood test, Miss Gibson. Second clinical examination, Dr. Goodall. Sixth experiment in group respiration chamber.

January 14, Squad B. In Boston; at Laboratory part of morning. Regular morning psychological program. All meals controlled.

Jan. 14 to 29, inclusive, Squad A. Seventh digestion period for collection of feces. (Period for *Kon*, January 15 to 29, inclusive.)

Jan. 15 to 22, inclusive, Squad B. Digestion period for collection of feces. The only digestion period for this squad.

January 19, Squad B. Came to Boston; dinner and supper at restaurant. *Kim* had (controlled) supper January 18 and breakfast January 19 in Boston. Regular evening psychological program. First skin temperature measurements. Individual 5-minute practice on treadmill. Third blood examination, Miss Gibson. Third clinical examination, Dr. Goodall. Seventh experiment in group respiration chamber.

January 20, Squad B. In Boston; at Laboratory part of morning. Regular morning psychological program. All meals controlled. (*Wil* had dinner and supper in Boston.)

January 25, Squad A. Tom had supper in Boston (controlled).

January 26, Squad A. Came to Boston; dinner and supper at restaurant. *Tom* also had breakfast in Boston (controlled). Regular evening psychological program. First skin temperature measurements. Individual 5-minute practice on treadmill. Third blood examination, Miss Gibson. Eighth clinical examination, Dr. Goodall. Ninth experiment in group respiration chamber.

January 27, Squad A. In Boston; at Laboratory part of morning. Regular morning psychological program. All meals controlled.

January 27, Squad B. Came to Boston; lunch on train, supper at restaurant. *Sne* and *Kim* had (controlled) dinner and supper, January 26, and breakfast and lunch, January 27, in Boston. Evening psychological program for eighth and last time. Second and last skin temperature measurements. Second Du Bois body-surface measurements. Second shadow photographs. Fourth blood examination, Miss Gibson. Fourth clinical examination, Dr. Goodall. Eighth experiment in group respiration chamber. Last day of controlled diet for *Squad B*.

January 28, Squad B. In Boston; at Laboratory during morning. Last rectal temperature and pulse-rate records, with subject in post-absorptive condition and in lying position. Standing experiments portable respiration apparatus; second record of pulse-rate and also blood pressure, with subject in standing position. Second series of experiments with treadmill; increased number of pulse records during and following walking experiments; records of blood pressure with subject standing and then sitting after walking. No psychological measurements, but strength of grip taken. Each man without food until the observations were completed, and then ate freely of food provided.

February 1, Squad A. Gymnastic exercises and diving registered by means of motion pictures. Arm-holding, 2.28 to 3.28 p. m., in competition with squad selected from college body.

February 2, Squad A. Last day controlled meals. Last experiments with respiratory-valve apparatus and portable respiration apparatus, Springfield. Came to Boston; dinner and supper at restaurant. *Tom* had dinner in Springfield (controlled). Electrocardiograms on *Kon, Gar, Pea,* and *Vea* at Laboratory at 4 p. m. After evening meal at restaurant, tenth evening psychological program. Subjec-

February 2, Squad A—continued.
tive impressions regarding clothing, feeling of cold during experiment, hunger, etc., recorded. Second (last) skin temperature measurements. Fourth blood examination, Miss Gibson. Ninth clinical examination, Dr. Goodall. Third Du Bois body-surface measurements. Fourth shadow photographs. Tenth experiment in group respiration chamber.

February 3, Squad A. In Boston; at Laboratory in morning. Last rectal temperature and pulse-rate measurements with subject in post-absorptive condition and in lying position. Standing experiments, portable respiration apparatus, with records of pulse-rate; blood pressure of subject standing. First treadmill experiments; pulse-rate standing, walking, and sitting. Blood pressure of subject standing after walking and then sitting. No psychological measurements, but strength of grip taken. Each man without food until the observations were completed, and then ate freely of food provided. No observations of any kind with *Squad A* after this date except records of body-weight, pulse-rates (not in post-absorptive condition), strength of grip, and introspections.

Feb. 8 and 9, Squads A and B. Interviews with men to obtain post-diet impressions, and especially information regarding influence of low diet on sex expression and tendencies.

February 18, Squad A. Last bicycle ergometer experiments.

February 20, Squad B. Last bicycle ergometer experiments.

March 6, Squad B. Last records of pulse-rate by Professor Johnson, with subject in lying position and with food.

March 7, Squad A. Last records of pulse-rate by Professor Johnson, with subject in lying position and with food.

May 21 and 22. Information obtained about college grades of *Squad A.* Interviews with six members of *Squad A* who still remained in college. Records of body-weight, pulse-rate, and strength of grip secured.

METHODS AND APPARATUS USED IN THE RESEARCH.

While much of this research followed established usage with regard to techniques, particularly in analysis, many of the procedures employed were either so fundamentally novel or important modifications of procedures previously described that, for a clear understanding of the data, it will be necessary to describe the techniques in considerable detail. One must assume that it is not permissible to publish data secured by an apparatus, technique, or method that has not been published or is not simultaneously published. On this basis, therefore, the report of this research must include the description of a considerable amount of new apparatus. On the other hand, in order to make the picture perfectly clear, it seems desirable to record, at least in brief, the methods employed for some of the simpler procedures, although no claim is made for originality in any of these well-known techniques.

The methods in the research as a whole may be classified under several heads: the control, preparation, sampling, weighing, and analysis of food; the collection, preservation, sampling, and analysis of feces and urine; the grosser physical measurements, such as weight,

height, surface area, and body photographs; records of muscular activity so far as they could be made; clinical examination, including blood pressure, blood examination, records of pulse-rate and body temperature; measurement of the gaseous metabolism; quantitative measurements of muscular work; and measurements of the neuro-muscular processes. Under these several heads, the measurements of gaseous metabolism, body temperature, muscular work, and neuro-muscular processes were, in general, carried out with essentially new techniques, some of the apparatus and methods being specifically designed for this research. All of the techniques have been subjected to severe control tests, not only prior to but during the progress of this research.

MISCELLANEOUS METHODS AND MINOR APPARATUS.

FOOD CONTROL.

Since the fundamental prerequisite of the research was an accurately controlled and definite knowledge both of the character and the amount of the food intake, Squad A was given a special "training table" in Woods Hall, the large mess hall of the college. Special waiters were assigned and representatives of the Laboratory staff were present at every meal and personally supervised all the food issued. The 12 men occupied regular seats at the table, which was pleasantly located in one corner of the dining room, with a minimum of confusion due to the passing of other waiters and other members of the college body. A psychological point that was not realized at the time, but developed later, was the desirability of avoiding the display of food served *ad libitum* at the other tables. We believe that if a private dining room had been used, it would have helped materially, for the lavish display of food within 5 or 6 feet of the dieting squad was at times distracting, to say the least. Convenient to the serving table were side tables for weighing, sampling, and keeping the records, and special utensils such as dishes for sugar, butter plates, etc.

Mr. Edward L. Fox was primarily in charge of the dietetic apportionment at the training table. His skill and diplomacy secured not only extraordinary accuracy in sampling and intelligent records, but he was *persona grata* with the entire squad during the research. During the diet-reduction period of Squad B, Mr. Fox had the intelligent cooperation of Mr. Harry Silverman of the Laboratory staff.

KINDS OF FOOD SERVED.

To minimize labor in the preparation of special foods or combinations of foods, and yet maintain the variety and palatability of the food supplied, it was decided at the outset to serve to the squad practically all articles of diet regularly served in the dining room at any given meal. Slight deviations from this rule occurred occasionally when substitutions were made for a part of the regular menu, or infrequent additions,

but in general the quality of the food was not altered. The curtailment of the diet was therefore wholly in the quantity served and not in the kinds of food. In other words, the men were served the same food, but were given what might be termed "half portions." The food in Woods Hall meets the strictest sanitary requirements for care in preparation and service, is well cooked, and is relished by the entire student body. The whole undertaking is a most successful undergraduate cooperative venture.

METHODS OF WEIGHING AND APPORTIONING.

The portions of food served to subjects were either weighed at the time or measured in carefully calibrated vessels or dishes. There were no estimated weights. To provide representative samples of the entire meal for analysis, two enamel dishes holding approximately 1 liter were labeled respectively "thirteenth man" and "fourteenth man." An equivalent weight of such food materials as were served to the individual members of the squad was placed in each of these dishes; the samples thus represented the kind and amount of food actually served to the members of the squad. Certain staples, such as butter, jelly, sugar, etc., were generally omitted since repeated analysis had shown their uniformity in composition.

At the beginning of the research, to simplify matters, all the men were served exactly the same quantity, so the amounts apportioned to the thirteenth and fourteenth men, respectively, represented exactly that served to each member of the squad. Subsequently, additions were made to the basal ration in certain cases, particularly when the loss in weight was too rapid or when the loss in weight was as large as was desired and the period of feeding for weight maintenance began. In general, however, the selection of food was such as to make the basal diet essentially the same for all the men, the supplementary amounts being usually supplied by standard materials such as sugar, butter, etc. When a special dish was served and one or two members of the squad were unable to eat it, weighed portions of the food were sent to the Nutrition Laboratory, where special analyses were made for subsequent calculation of these necessary deductions.

The food samples were practically all collected in quart fruit jars and sealed with a rubber ring and glass top. One jar would contain one or two meals, according to the amount of food served per day, but each meal was given a separate number and the samples in the thirteenth and fourteenth pans designated as "*a*" and "*b*."[1] This system of sampling in duplicate was followed throughout the entire 4 months of the observation.

The jars for the samples were shipped at frequent intervals in cases so constructed as to provide against breakage. One of the most

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[1] See table 30, p. 266.

annoying features in the whole investigation was the inordinate delay in the express delivery between Boston and Springfield. Considering the unusual demands put upon the express companies, the irregularity in train service caused by extra heavy shipments of munitions and coal, and the extraordinarily severe winter of 1917–18 in New England, we should perhaps be congratulated on receiving all the samples. Occasionally samples would be received in a condition of incipient fermentation owing to delay in transit, but in no instance did the fermentation reach such a stage as to justify us in believing that an appreciable loss of energy had taken place. Another difficulty was the fact that with relatively large amounts of milk and occasionally cocoa, samples were sometimes frozen; occasionally the freezing resulted in breakage of the glass bottle. Fortunately in no instance were both samples *a* and *b* destroyed by the breakage of the bottle from rough handling in shipment or from freezing.[1]

All of the energy in the food consumed by the squad was supplied at the table, with the single exception of chewing gum. It was soon found that chewing gum was much desired by a large number of the squad. At first it was considered that this could be permitted *ad libitum*, but later we became aware of the fact that each stick of chewing gum contained 2 grams of soluble carbohydrate, corresponding to an energy content of approximately 8 calories. It therefore became necessary for us to record accurately the amount of gum used by each subject, and the subjects were asked to report three times daily the amount of gum chewed. This statement of gum used forms an integral part of our system of records.

Approximately once every two weeks the men were allowed to eat two meals uncontrolled, usually the dinner and supper on the Sundays following their return from a series of respiration and psychological experiments made at the Nutrition Laboratory in Boston. The kinds and approximate amounts of food eaten at these meals were reported by the men each time. As these reports were entirely uncontrolled, they have only an approximate value. This biweekly freedom, though slight, was much enjoyed by the men and appeared to be psychologically desirable. When one considers that these men were under observation day after day, almost from hour to hour, for a period of 4 months, it will be seen that a certain degree of relaxation, other than that secured at Christmas and Thanksgiving, was absolutely necessary. The reports of the meals made by the men are reasonably clear and certainly serve to give an approximate estimate of the amount of protein and energy of the food eaten.

In addition to the controlled meals at the regular diet table, every visit to Boston resulted in at least two controlled meals there, one at a

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[1] Usually samples *a* and *b* were shipped in separate boxes.

local restaurant which provided a special table for the 12 men and served a prescribed menu. Here again the portions for the thirteenth and fourteenth men, respectively, were placed in pans and subsequently analyzed. Since the diet used on the periodic visits to Boston at this restaurant was substantially the same for every visit to Boston, the control was admirable on the probable value of protein and energy in the diet served the subjects at the restaurant.

Each morning of these Boston experiments, a standard simple breakfast was served in the Laboratory. The diet for this breakfast also remained unaltered throughout the entire period of experimenting and was frequently analyzed and its composition checked. The preparation of the breakfast was left in the careful hands of Mr. Henry W. Fudge of the Nutrition Laboratory staff.

Occasionally it became necessary for the men, particularly late Sunday afternoon, to eat a light lunch away from the training table. This lunch always included some standard material, frequently a standard brand of cake chocolate and sweet cake or cookies; samples of these were weighed, analyzed, and carefully controlled.

COLLECTION AND SEPARATION OF FECES.

Although, with normal young men having presumably normal digestion, standard factors for digestibility of our common food materials may be used to compute the probable fecal output of nitrogen and energy per day, it seemed necessary, when there were to be material reductions in the diet, not to assume that there would necessarily be the same proportion of energy and nitrogen lost through the feces as would commonly occur with people subsisting upon full diet. Consequently arrangements were made to obtain representative samples of feces from time to time. It was impracticable, owing to the long period of the investigation, to collect the feces for the entire time. Such collections were made at the beginning of the experiment and approximately every other week throughout its continuance. The length of each period for the collection of feces ranged from 3 to 16 days.

The feces were collected in numbered sheet-iron pans, one of which was assigned to each member of the squad; care was taken to avoid loss of urine at the time of defecation. The pans were covered with tin covers and the subjects carefully instructed, especially at the beginning and end of the period of collection, to indicate the first portion of feces passed.

The separation of feces was made by administering a marker of some kind. At first powdered charcoal or lamp black was used, but later, in accordance with the extended experience at Battle Creek Sanitarium, carmine was employed. Markers were put in gelatine capsules and 3 capsules were given simultaneously according to the following schedule: On the day of the first collection of feces, the marker was given before

breakfast; the feces colored with the carmine or charcoal were then considered a part of the feces belonging to the collection period. At the end of the collection period, a marker was given with the following breakfast and feces preceding the colored portion included in the feces for this period.

After the separation of the colored portion of the feces, the portions to be analyzed were placed in glass jars in exactly the same manner as the food samples were handled, 5 c.c. of concentrated hydrochloric acid added to each jar and shipments made in special cases to guard against breakage.

Constipation.—As a result of the marked reduction in diet, constipation was of frequent occurrence, especially in the earlier stages of the research. To offset this and profiting again by the extended experience at Battle Creek Sanitarium, bran was administered in amounts desired by the subjects. While practically all of the men were entirely unused to bran, nearly all of the subjects asked for it and in rather large amounts. Indeed, so much bran was taken that our attention was called to the fact that this substance, instead of being mostly indigestible fiber, contained a really large amount of available energy. Consequently we found, much to our chagrin, that no small part of the energy in the diet was supplied by the large amounts of bran used which should therefore be taken into account. It thus became necessary either to curtail the use of bran or to substitute it for other food materials.

In rare instances the subjects resorted to some simple physic, as salts or oil. In no case was oil used during the periods when feces were collected; the energy of the feces was therefore not contaminated by the energy of unabsorbed petroleum oil. Patent preparations containing bran in various forms, such as biscuits, were liked by the subjects and these, combined with an extensive use of bran, readily served to hold constipation in check. Chef Hall also made some excellent bran muffins which were greatly relished not only by the squad but by the entire student body. The diet was further modified in the latter part of the period by the use of somewhat bulky food materials, such as spinach, which supplied coarse ballast. By these simple dietetic means constipation was controlled.

COLLECTION OF URINE.

The importance of noting the nitrogen output during this period of undernutrition led us to emphasize especially to the squad the necessity for the complete collection of the urine for the entire period of the research, or at least this was held up as an ideal. Each man was told that the best and most perfect picture of the balance of income and outgo of nitrogen could be obtained only by the faithful collection of all the urine. The fact that we were able to secure practically every day 24-

hour quantities of urine for 12 to 25 men during a period of 3 to 4 months is indubitable evidence of the fidelity of the men in this rather tedious and embarrassing part of their cooperation. It involved in many instances carrying special containers or in an emergency purchasing special bottles, but in spite of all these inconveniences the squad were extraordinarily faithful in living up to the ideal of collecting the entire amount of urine.

Usually the experimental day was ended, so far as the collection of urine was concerned, from 5 to 6 o'clock in the morning, when the men appeared for weighing and for the measurement of the gaseous metabolism. The entire collection of urine was mixed in one 24-hour specimen, which was carefully measured and checked by a second observer. A 130 c.c. sample was then bottled, carefully labelled with dates, times, etc., and shipped in special shipping cases, with provisions to avoid breakage and, when necessary, freezing. Notwithstanding our care, one shipment was lost from freezing. After this happened, the original cases containing the urine bottles were packed inside of a larger case and the intermediate space filled with sawdust.

PREPARATION OF SAMPLES OF FOOD AND FECES FOR ANALYSIS.

The samples of foods and feces received from Springfield at the Nutrition Laboratory in the quart glass jars were first carefully weighed and checked, then transferred to previously weighed white enamel pans, and dried to approximately constant weight. To accomplish the drying of the large number of food samples, which were somewhat larger than the usual samples dried, also the large number of feces, required a specially constructed oven. This oven, which is shown in detail in figure 1, consists of an asbestos-walled cabinet with doors that open in front and stout wire-gauze shelves. At the top, through an 8-inch furnace pipe, air was thrown out by means of an electric fan placed in the pipe. At the bottom of the chamber an 8-inch furnace pipe led air from the room into the oven; the air was heated by means of a large gas burner of rose pattern. By regulating the speed of the electric fan and the flow of gas, the temperature could be kept at approximately 70° C. the entire time. Throughout the whole period of 4 months, there was rarely difficulty with the temperature control. As fast as the foods were partially dried, they were stirred, a fresh surface was exposed, and the samples were moved about in the oven so as to take advantage of the greatest heat and the greatest volume of air.

When the samples were thoroughly dried so as to be in condition for grinding, they were allowed to reach room temperature and stand in the room for 24 hours or more. They were then weighed, put through a hand mill or meat chopper one or more times, and finally bottled either in the regular glass jars or in smaller glass jars, with stoppers, ready for analysis. At this stage the recorded weights of the dried

samples, *a* and *b*, could be compared and notation made of marked discrepancies, if any existed. Theoretically both samples should have dried to essentially the same weight.

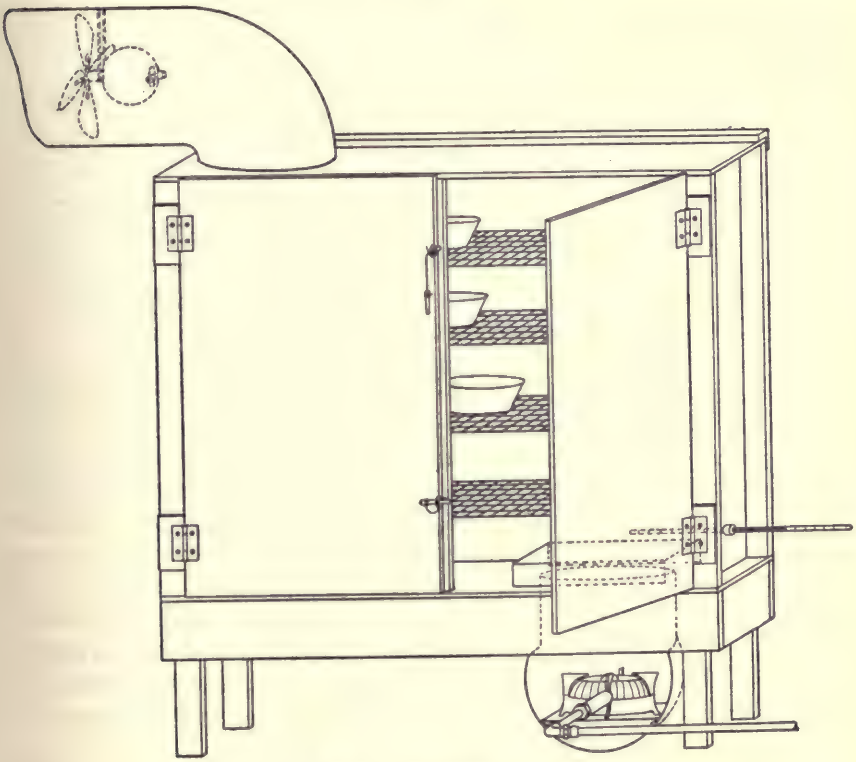

FIG. 1.—Drying oven.

The walls and doors of this oven are of asbestos board and the shelves are of strong wire mesh. A rose burner in the air intake at the bottom furnishes the heat; the temperature of the oven is indicated by a thermometer at the side. Ventilation is secured by a fan placed in the exit pipe above the oven.

METHODS OF ANALYSIS.

URINE.

Observations on the urine were confined to the crude observations of specific gravity with a standard spindle and to the exact determination of nitrogen by the Kjeldahl process. The Laboratory is well supplied with automatic pipettes, digestive apparatus, and stills for the most rapid work. The 1,000 or more urine analyses involved in this research were made exclusively under the supervision of Miss Elizabeth B. Babcock, and were carried out with extraordinary fidelity, rapidity, and accuracy. In this work she was assisted by Miss Marion L. Baker and Mr. Harry Silverman.

FOODS AND FECES.

The dried samples of foods and feces were analyzed for total nitrogen by the Kjeldahl process. Here again the nitrogen content of samples *a* and *b* supplied a check upon each other.

HEAT OF COMBUSTION.

To obtain an energy balance, it was necessary that we should find the actual calories in the intake of food. Of the output it was possible for us to determine only the calories in the feces. Since, however, there are reasonably constant standard factors for computing the calories from the percentage of nitrogen in urine, we resorted to this method rather than attempt to dry down the 1,000 or more samples of urine obtained in the research and determine the heats of combustion with the bomb calorimeter. The daily output of energy in urine was found by multiplying the total number of grams of nitrogen by the factor 8.0. The energy as thus calculated was almost invariably somewhat under 100 calories, so that the error due to the method cannot at best be an appreciable portion of the total energy under consideration for the day.

The heats of combustion of the feces and dried foods were determined with a bomb calorimeter of the Kroker type in an adiabatic calorimeter. This calorimeter was developed in the Nutrition Laboratory and promotes rapid operation.[1] The technique was finally so adjusted that after the various dried pellets of feces and food had been prepared and weighed and placed in nickel capsules, Miss M. A. Corson and her assistant were able to determine and compute four heats of combustion per hour. This made it possible to complete this extensive series of determinations within a reasonable time.

Since the total nitrogen and calories were obtained, it was deemed unnecessary to make an exact apportionment of the energy of the intake between protein on the one hand and fat and carbohydrate on the other. It is perfectly possible, knowing the total caloric value and nitrogen of the intake, to compute the calories due to protein. The remainder will be due to fat and carbohydrate. These were all mixed diets, with no special dietary adjustments other than decrease in the portions served. It hardly seemed advantageous to determine the fat in the food intake; indeed, the time requirement for such determination for all of the samples would alone preclude this additional work. A few special fat extractions were made which will be mentioned in the text from time to time, but there was nothing to indicate that exact information regarding the relative proportion of calories from fat and carbohydrate would have a special significance in the discussion of the results.

[1] Benedict and Higgins, Journ. Am. Chem. Soc., 1910, 32, p. 461.

BODY-WEIGHT MEASUREMENTS.

Since it was impossible to establish the complete measure of the income and outgo of each of these men in a respiration calorimeter of sufficient size to enable them to carry on physical activity comparable to their ordinary collegiate activities, it became necessary for us to rely in the last analysis upon the changes in body-weight as an index of the nutritive condition. For short periods nothing could be more erroneous than to follow this rule. The literature is full of illustrations of undue emphasis being placed on either considerable changes in body-weight or on slight changes incidental to alterations in diet. As is well known, since the body contains so large a proportion of water, a change of 1 or 2 kg. in body-weight may be in large part due to changes in water content and not to a change in the amount of organized body-tissue. Still in this research body-weights determined over a long period of time could fairly be taken as indices of the condition of nutrition. Since they were so important a factor in noting the effect of the reduced diet, it was increasingly necessary to take unusual precautions as to accuracy, regularity of record, and suitability of technique.

The body-weights were all taken in the early morning, with the nude subject in the post-absorptive condition and after the bladder had been emptied. This did not make allowance for undischarged fecal matter, but with the average individual these variations would not be very great, especially over a long period. One of our subjects, however, *Pec*, defecated regularly but once every 5 days; it is important to note that his body-weights may be affected by the presence or absence of a large amount of fecal matter in the colon. The subjects were weighed either upon a platform balance of unusual sensitivity (the so-called "silk scale" manufactured by the Howe Scale Company, with a capacity of 150 kg. and a sensitivity of 10 grams) or, as was done in the latter part of the test, upon an accurate and carefully calibrated spring platform balance. The latter balance, which is manufactured by John Chatillon and Sons, is designed especially for recording body-weights, and has a large dial which can easily be read to 0.25 kg.; a large number of body-weights were obtained with this balance. The records of the body-weight were checked by some member of the Laboratory staff. In no instance was an individual record made by the subject or an unchecked figure recorded.

BODY-SURFACE MEASUREMENTS.

Measurements of body-surface were made in all cases. It is greatly to the credit of D. and E. F. Du Bois that their methods for body-surface measurements have been so carefully outlined that relatively little training is necessary to secure accurate measurements of the

dimensions required. These measurements were made frequently for all of our subjects, not only to find the exact body-surface, but also to indicate a typical series of representative circumferences that could be studied with a view to noting the diminution in volume of the body as the weight loss progressed. The heights were measured carefully on a standard scale. Both the Du Bois measurements and the records of the heights were made independently by two observers and every reading of the tape or measuring-rod was checked.

ANATOMICAL PHOTOGRAPHS.

The Du Bois surface measurements were also useful in noting whether there was uniform agreement between the surface measurements as thus made and anatomical photographs of the subject, in accordance with the singular relationship noted in the Nutrition Laboratory a year or two ago.[1] It was observed that when the shadow of the body in a certain lateral pose was planimetered and compared with a photographed meter scale, the area thus computed bore a striking proportionality to that measured by the Du Bois linear formula. Even with the most diverse configuration of body and grotesque shapes this uniformity held true. To provide a double check upon the accuracy of the Du Bois measurements and to show at a glance the general anatomical condition of these men prior to and subsequent to the period of reduced diet, a set of profile photographs was made for each subject. Only one pose (pose C) was used.[2] These photographs thus served, first, to indicate directly the general configuration of the body of the subject studied; second, to show the changes in configuration as the loss in weight progressed; third, to supply interesting comparisons for the area as determined by the planimeter for comparison with that computed from the Du Bois linear formula.

ACTIVITY RECORDS.

Although the pronounced influence of various forms of muscular activity upon the total metabolism and hence upon the total demands for food is so great, it was admitted at the outset that exact records of muscular activity of a group of 12 to 25 men, though desirable, were impossible. On the other hand, since it could not be assumed that all the men would have the same degree of muscular activity, we believed that we should make every effort to obtain a quantitative idea of relative, if not absolute, activity of the various members of Squad A. Records made with the pedometer gave a crude index which was of great assistance and not without quantitative value. All of the subjects were provided with pedometers, which were worn continuously and which were read

[1] Benedict, Am. Journ. Physiol., 1916, **41**, p. 275.
[2] Pose C gives a profile view (from the left) of the subject standing at "attention," with the left arm extended and the fingers separated. (See figs. 74 to 85, p. 240.)

once or twice each day and the results carefully recorded. Ideally each pedometer should have been set to accord with the uniform length of step for the individual subject, but it was not feasible.

Many of the subjects were unusually interested in physical activities and some were specially proficient. Frequent reference is made in their personal histories to incidents calling for unusual muscular activity. Thus, some of our men ran in cross-country teams, others devoted considerable time to instructing gymnasium classes, swimming, tennis, football, hockey, or bicycle riding. Records were made of this unusual activity. Finally, one of the college instructors outlined in another connection a course in personal efficiency, which called for an exact cataloguing of each day's activities and approximated in a way a gross motion study. The personal records of the few of our squads who took the course are of special interest for comparison with other men who took the course but were not on diet, as they indicate to what extent the members of the reduced diet squads lived up to the physical and mental activities of their college mates. The men were urged not to curtail their college activities, either intellectual or physical, and while we could have absolutely no control in this matter, we believe that, in general, they did not try to save themselves. In several instances we are perfectly certain that activities were curtailed and in other cases, particularly during the period when extra efforts were made to reduce weight, the physical activity of some men greatly exceeded that usual for them and surpassed that of their fellow students. These personal records are therefore of unusual assistance as an indication of the validity of the comparison of the men on this squad with their confrères.

CLINICAL EXAMINATION.

It was not sufficient to assume that our subjects were healthy young men or, as in earlier researches with normal individuals, "presumably in good health," but the changes possibly resulting from the reduced diet were considered of sufficient moment to be noted by an expert clinician in an ordinary routine clinical examination. It was our good fortune to enlist the interest of Dr. Harry W. Goodall, who made a careful and helpful study of the subject of the prolonged fasting experiment reported from this Laboratory in 1915.[1] Dr. Goodall saw the men in Squad A at practically every visit to Boston, but unfortunately could not observe them prior to the commencement of the reduced ration. The men began the reduced diet on October 4, 1917; Dr. Goodall's first examination was on October 13, 1917. Squad B was likewise examined on January 5, prior to restriction in diet, and subsequently when living on the reduced diet. The examination was carried out according to the methods used by our foremost clinicians.

[1] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915.

BLOOD EXAMINATION.

Through the kindness of Dr. George R. Minot, we secured the assistance of Miss Anna L. Gibson, superintendent of the Huntington Memorial Hospital, Boston, and her associate, Miss Myra B. Conover, who made the routine blood examinations of the subjects in both squads from December 19, 1917, to the end of the observations. Here again this series of examinations was unfortunately not begun early enough to secure normal values on Squad A, although they were obtained on Squad B before and during the reduced diet period. Both the red and white blood counts were made with the Thoma-Zeiss counting chamber. The hemoglobin was determined with the Sahli hemometer. It is important to note that the instrument used in this research gave low values for normal blood, *i. e.*, about 85 per cent.

BODY TEMPERATURE.

The temperature was taken in the mouth every morning while the men were lying on the couch preparatory to respiration observations at Springfield. These temperatures will not be reported, as they are physiologically of no significance other than to demonstrate that the temperatures were normal. Toward the latter part of the research it was made a general rule to obtain the rectal temperatures when the men were inside the large respiration chamber in Boston, just prior to their rising in the morning. These were made with 12 sensitive clinical thermometers, calibrated with a standard thermometer made by Richter of Berlin.

During the last few weeks of the research an apparatus for recording the surface temperatures of the skin was installed in the library at the Nutrition Laboratory, with which the temperature of the forehead and of the backs of the hands was taken with a thermo-couple. This thermo-couple consisted of a copper-constantan junction, one end of which was kept in a Dewar flask at approximately 34° C., the temperature being read to hundredths. The other end of the junction, which was in the shape of a hairpin and protected with a thin layer of cotton wadding to prevent the influence of external temperature, could be applied to the surface of the skin. The thermo-junctions were connected with a sensitive Deprez-d'Arsonval galvanometer and the readings taken. It was soon found that the deflections of the galvanometer pursued a clearly characteristic course and a point could easily be found which represented in all probability the true skin temperature. These observations were made for all the subjects at various times and quite frequently were controlled by measurements obtained on several members of the Laboratory staff. Sometimes, also, visitors were measured to assist in the interpretation of the results.

ALVEOLAR AIR.

The determination of the alveolar air tension was made with a modified form of the Haldane apparatus on samples of alveolar air obtained by a method previously described.[1] In this method of collection a 3-way valve is used which is attached to a 6-foot length of rubber tubing and a mouthpiece. The subject at first breathes through the short arm of the valve, and is cautioned to breathe normally and no deeper than usual and to hold the lips firmly about the mouthpiece. While he breathes through the side opening of the valve the operator watches the rise and fall of the chest or abdomen. At the end of an expiration, the time is noted and the valve is turned to such an angle that the subject breathes quietly into the long rubber tube. After 20 seconds and at the end of an expiration, the valve is turned back quickly to the original position. At the usual respiratory rate, 20 to 22 seconds will allow for 4 or 5 respirations. A small light feather fastened across the outlet of the long tube will indicate by its movements the end of the expiration. After the valve is turned, the samples are quickly drawn from the rubber tube through an aperture near the valve and analyzed as usual by the Haldane method. Prior to the second test, the long tube is thoroughly ventilated to expel the residual air from the preceding respirations. The results for each test are based on the average of the analysis of two samples taken successively.

TECHNIQUE FOR DETERMINING GASEOUS METABOLISM DURING REST.

The considerable amount of experimental attention given to the technique for determining the gaseous metabolism led, as would be expected, to an unusual extension of the gaseous metabolism measurements. When the experiment was first proposed, it was intended to obtain occasional records of the respiratory exchange for the individual men. As the program developed, it appeared desirable to get as frequent records for each man as possible. Therefore all of the facilities of the Laboratory were drawn upon to meet the emergency of having to determine the gaseous metabolism of 12 men as nearly as possible once each day. It was believed that in some of the observations, methods could be used in which a high degree of accuracy might be sacrificed to expedition, but it was also desirable to make determinations of the respiratory exchange by means of thoroughly tested standard methods, if only rarely. Finally, it was planned to make observations of the squad as a whole in a newly perfected respiration chamber in the Nutrition Laboratory in Boston, which had been thoroughly

[1] Roth, Journ. Am. Med. Asso., 1915, **65**, p. 413; also Boston Med. and Surg. Journ., 1918, **179**, p. 130.

tested in a series of observations with a group of approximately 25 individuals several months before.

RESPIRATORY-VALVE METHOD.

For the most reliable measurements of the basal gaseous metabolism we took advantage of the newest technique developed in the Laboratory. This included the use of a special form of mask, Thiry-Tissot valves, a spirometer, and the Haldane gas-analysis apparatus. By means of two spirometers it was possible to obtain the gaseous metabolism in at least two periods each on two men every morning, thus securing observations on each member of the squad at least once a week. In the last few weeks of the research, the routine was so altered that measurements were obtained with this procedure on three men each morning. While the various sections of the apparatus have been extensively described by Dr. T. M. Carpenter of the Nutrition Laboratory staff,[1] the exact combination of appliances used (due, as a matter of fact, to the technical skill of Dr. Carpenter) has not been described *in extenso* and a few words are here desirable.

Believing that for the most accurate measurement of the respiratory exchange and especially the respiratory quotient, untrammeled respiration is desirable, Dr. Carpenter has used a face mask provided with inlet and outlet valves which communicate, in turn, with a pipe leading to the outdoor air and another pipe leading to a Tissot or similar type of spirometer. By means of a small canvas cap and suitable straps, this mask can be so firmly attached to the face as to make it air-tight. With reasonable care in application, the mask will be sufficiently comfortable for the subject to wear it for a half hour or more; occasionally the subjects fall asleep—a proof of absence of discomfort.

As used in the daily observations with Squad A, the mask was first attached and the valves examined to find if they were working smoothly. The expired air was then allowed to pass into the room for several moments, but at a given time connection was made with the spirometer and the air expired by the subject was collected in the spirometer for a period of approximately 10 minutes. To provide exact information as to the degree of repose of the subject, as well as graphic records of the respiration, two pneumographs were placed one about the chest and the other about the thighs; these were connected with suitable tambours which recorded upon the smoked surface of a kymograph drum. By this method the activity was instantly recorded, also each respiration. By means of the respiration record, the character as well as the rapidity of the respiration could be seen. Finally, the importance of knowing whether the subject was asleep or awake during the observations led us to obtain by means of a signal magnet writing upon a kymograph drum records of the responses to a stimulus given

[1] Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, p. 61.

the subject every minute automatically by a clock. The clock was in a closed electric circuit, which caused a buzzer to vibrate for a fraction of a second. If the subject was sufficiently awake to respond to this signal, he pressed a small push button held in his hand; this movement was recorded on the drum.

At the end of the 10-minute period of collection of expired air, the time was accurately noted and the tube leading to the spirometer disconnected. Connection was then made with the second spirometer and the expired air collected during a second 10-minute period. Throughout both periods the pulse-rate of the subject was frequently counted by another observer.

While the second spirometer was being used, the height of the first spirometer, the temperature, and the barometer were recorded. A sample of the air in the spirometer was also collected in small Haldane samplers over mercury, properly numbered, and placed in suitable racks for subsequent analysis. Usually three samples were taken from each spirometer. The total volume of air expired in each of the two 10-minute periods could be computed from the height of the two spirometer bells. These volumes could be corrected to 0° C. and 760 mm. by suitable calculations. Using these volumes and the number of respirations per minute as obtained from the kymograph records, the total volume of air expired per minute and the total volume per respiration could be accurately determined.

The gas analyses were all made with the small Haldane portable apparatus. Two of these were kept in perfect condition for the purpose and analyses frequently made on both for control. Furthermore, the gas analyses each day were preceded by an analysis of outdoor air; until satisfactory values were found for both carbon dioxide and oxygen in these air samples, the analyses of the gas samples were not made. The gas-analysis technique was carried out by Miss Mary F. Hendry, of the Nutrition Laboratory, whose long training, particularly under the skilful guidance of Miss Alice Johnson, has made her one of the best gas analysts that the Laboratory has ever had on its staff.

With two and in the latter part of the research three subjects, each observed for two 10-minute periods, the usual duplicate analyses for each spirometer would require a total of 8 analyses with 2 subjects and 12 analyses with 3 subjects. It was early found, if the sample from one spirometer was analyzed and the complete oxygen intake and carbon-dioxide production computed from this one analysis, and a sample from the second spirometer analyzed and the complete oxygen intake and carbon-dioxide output computed from the results of the analysis, that in the large majority of cases, one could rely upon a single analysis of the air sample from each spirometer and assume that the accuracy of the whole physiological and chemical process was established by the agreement of the two samples. This procedure was not followed until several days' verification of the method had proved its

uniformity. It is of interest to note that subsequently the cooperation of the subjects was so perfect, the technical skill of the operators so satisfactory, that duplicate analyses were rarely called for. Thus, the daily gas analyses (aside from the daily outdoor air control) could usually be completed after 4 analyses with 2 subjects and 6 analyses with 3 subjects.

The special care given to these measurements of the gaseous metabolism was fully justified by the unusual significance of the results. This procedure supplied us with the most exact picture of the transition in basal metabolism of the individual subjects from day to day as the reduced diet continued. It is the clearest picture of variations in the individual basal metabolism and likewise of the absolute values for the metabolism that we have throughout the whole study.

PORTABLE RESPIRATION APPARATUS.

The complexity, nicety of manipulation, and care required for metabolism measurements by means of a mask, valves, spirometer, and gas analysis, precluded the use of this method for more than two or at best three of the 12 subjects each day. On the other hand, it was agreed that changes of considerable importance might take place inside of a week which should be noted, if possible. Hence we employed a new type of respiration apparatus, which had been primarily developed for clinical work, but not extensively used in the Laboratory prior to this research.[1] By means of seven of these apparatus, specially constructed for the purpose, the measurements were extended each morning so that two observations were made with the respiratory-valve type of apparatus and seven with the new portable type. We thus obtained basal measurements for 9 of the 12 men daily.

GENERAL PRINCIPLE OF APPARATUS.

In the portable respiration apparatus, the subject breathes into and out of a confined volume of air that circulates through a series of purifiers which remove the carbon dioxide as fast as formed. As the air passes through the lungs of the subject, oxygen is absorbed from the air, with a consequent gradual decrease in the oxygen content. The decrease in the total volume of the air represents the volume of oxygen consumed.

The portable respiration apparatus consists of a mechanical blower to circulate the air, three bottles which contain purifying material to remove the carbon dioxide and water-vapor, and a spirometer with suitable piping and connections. The spirometer serves the triple purpose of providing (1) a suitable housing for the mechanical blower; (2) a fluctuating factor in the air-circuit to allow for inspiration and expiration, *i. e.*, an expansion chamber; and (3) a measure of the

[1] Benedict, Boston Med. and Surg. Journ., 1918, **178**, p. 667. The description, together with figures, is in large part reprinted from this article.

oxygen consumed by means of a direct reading of the level of the spirometer bell at the beginning and end of an experiment.

After leaving the air-purifying bottles, the air passes through a tube to the mouth of the subject. The expired air, containing carbon dioxide, is drawn through a large-caliber tube to the spirometer, from which

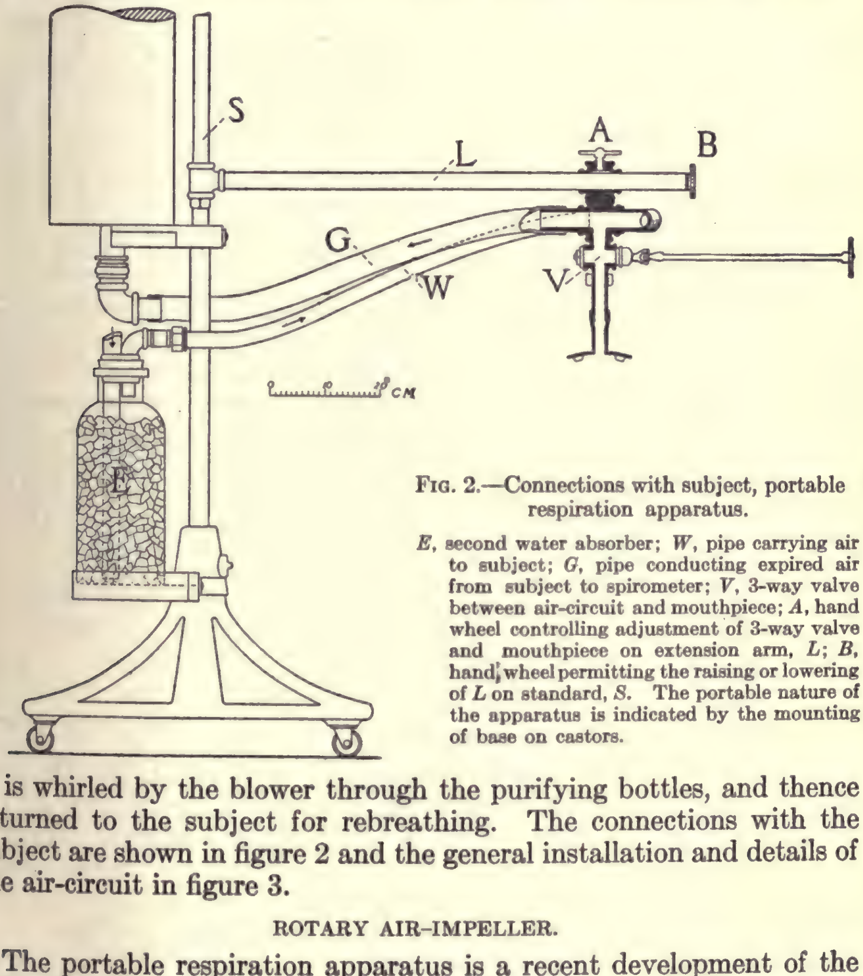

FIG. 2.—Connections with subject, portable respiration apparatus.

E, second water absorber; *W*, pipe carrying air to subject; *G*, pipe conducting expired air from subject to spirometer; *V*, 3-way valve between air-circuit and mouthpiece; *A*, hand wheel controlling adjustment of 3-way valve and mouthpiece on extension arm, *L*; *B*, hand wheel permitting the raising or lowering of *L* on standard, *S*. The portable nature of the apparatus is indicated by the mounting of base on castors.

it is whirled by the blower through the purifying bottles, and thence returned to the subject for rebreathing. The connections with the subject are shown in figure 2 and the general installation and details of the air-circuit in figure 3.

ROTARY AIR-IMPELLER.

The portable respiration apparatus is a recent development of the universal respiration apparatus,[1] but has many striking similarities to the early "oxygénographe" of Fredericq[2] and the later device of Krogh.[3] In at least one main particular, however, this apparatus differs from the earlier forms in that the air is circulated not by the lungs of the subject, but by an electrically-driven fan. There are no valves to be actuated by the lungs, and the fan does all the work of

[1] Benedict, Deutsch. Arch. f. klin. Med., 1912, **107**, p. 156; see also Am. Journ. Physiol., 1909, **24**, p. 345.

[2] Fredericq, Arch. de Biol., 1882, **3**, p. 687; also Éléments de Physiologie Humaine, Ghent and Paris, 1888, 2d ed., p. 141.

[3] Krogh, Skand. Arch. f. Physiol., 1913, **30**, p. 379.

circulating the air, passing it through the purifying agents, etc. The lungs are thus relieved of the labor forced upon them by many types of respiratory apparatus, and breathing is as free and untrammeled as is possible with any form of breathing appliance. The universal respiration apparatus requires a positive blower for the circulation of the ventilating air current, since considerable pressure is necessary to pass the air through the sulphuric acid used to remove the water vapor, but the absorbents employed in the new apparatus (calcium chloride and soda lime) offer no material resistance; accordingly a small rotary air-impeller may be successfully utilized. For this purpose a small hair-drier is employed which moves a considerable volume of air, but can not give positive pressure. This hair-drier is light in weight and provided with a universal motor so that it can be used with either alternating or direct current.[1] The blower must be oiled at least every other day when in constant use. To avoid possible leaks the blower is placed inside the spirometer.

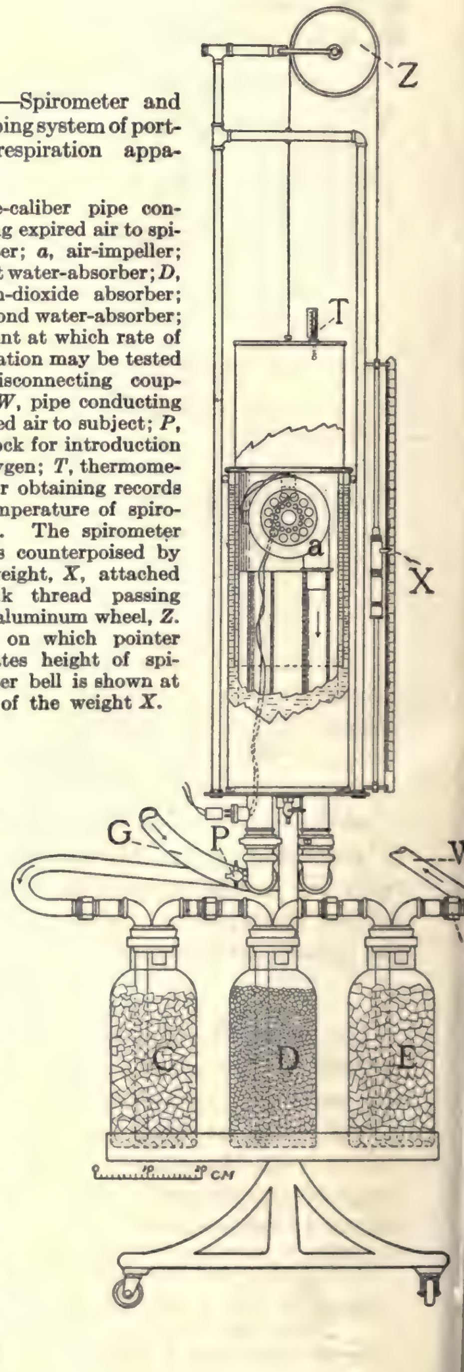

FIG. 3.—Spirometer and absorbing system of portable respiration apparatus.

G, large-caliber pipe conducting expired air to spirometer; *a*, air-impeller; *C*, first water-absorber; *D*, carbon-dioxide absorber; *E*, second water-absorber; *S*, point at which rate of ventilation may be tested by disconnecting coupling; *W*, pipe conducting purified air to subject; *P*, pet-cock for introduction of oxygen; *T*, thermometer for obtaining records of temperature of spirometer. The spirometer bell is counterpoised by the weight, *X*, attached to silk thread passing over aluminum wheel, *Z*. Scale on which pointer indicates height of spirometer bell is shown at right of the weight *X*.

AIR-CIRCUIT.

By reference to figures 2 and 3, it may be seen that the air leaving the mouth of the subject is drawn along a wide tube, *G*, enters the spirometer, and is discharged by the air impeller, *a*, into a calcium-chloride

[1] The hair-drier, which is manufactured by the Arnold Electric Co., of Racine, Wisconsin, is purchased without switch, heating unit, or handle, and slightly modified by adding a discharge tube to support the drier when in position inside the spirometer.

bottle, *C*, where the water-vapor from the lungs is removed. It then passes through a soda-lime bottle, *D*, in which the carbon dioxide is absorbed, and next to a second calcium-chloride bottle, *E*, where the water vapor from the soda lime is absorbed. The air, thus freed from both carbon dioxide and water vapor, is conducted through the tube *W* to a 3-way valve (*V*, figure 2) leading to the lungs of the subject.

Unless the volume of respiration is wholly abnormal, the rate of ventilation produced by the blower is sufficient to deliver enough purified air at the junction of the 3-way valve and the main air pipe to supply all that is needed, *i. e.*, approximately 30 liters per minute. If there is unusually rapid and deep inspiration, so that air is, for a moment, drawn back from the spirometer, the extra wide tube, *G*, provides a minimum resistance between mouthpiece and spirometer.

TEST FOR RATE OF VENTILATION.

The spirometer, when filled, holds about 7 liters. The rate of ventilation may be approximately determined by opening the system at the coupling, *S* (fig. 3), and pinching the tube, *W*, thus closing the intake tube. Air from the spirometer is then discharged by the blower at the open coupling, and the time in seconds is noted for the spirometer to fall completely (350 mm.). If 15 seconds is required for the spirometer to fall, the ventilation rate is approximately 28 liters per minute.

ABSORBING SYSTEM.

The calcium-chloride and soda-lime bottles are of simple form and, for convenience, are placed upon a shelf attached to the base of the apparatus. The soda lime is made by the formula of Haldane.[1] It has a distinct yellowish tint which changes to a chalky whiteness as the carbon dioxide is absorbed by the reagent. The efficiency of the reagent and the time for renewal may be judged by the progress of this change in color. When a determination of the oxygen consumption only is desired, as is usually the case, the calcium-chloride bottles may be dispensed with. A greater efficiency of soda lime is thus obtained, for it has been found that the moister the soda lime is, the greater is the absorption of carbon dioxide. Indeed, the expired air may be passed directly through the soda lime if care is taken that the excessive absorption of water does not make the absorbent so pasty as to interfere with the free passage of air. As this is a very important point, the ventilation rate should be frequently tested.

If the reagent becomes exhausted the physiological effect is a somewhat labored respiration due to the unabsorbed carbon dioxide acting as a stimulus to the respiratory center. This is not a serious defect and

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[1] Haldane, Journ. Physiol., 1892, **13**, p. 422. The prepared soda lime may be purchased from Stanley Jordan & Co., 93 Water Street, New York City.

usually has no quantitative significance in the measurement of the oxygen consumed in the 10 or 12 minute period. At the end of the period the motor must be run a few seconds longer to insure a complete absorption of the carbon dioxide in the air by the soda lime.

While the labored respiration is evident to the practised eye in a more rapid rate and a larger amplitude of the excursions of the bell, a pneumograph about the chest with attachment for a kymograph record supplies a good picture of the mechanics of respiration and instantly records dyspnœa. The excursions of the bell may be directly written on a kymograph by attaching a light pointer to the counterpoise, though the continuous upward trend of the curve as the oxygen is absorbed will permit of but short records on the kymograph drum of standard height.

SPIROMETER.

The spirometer used is a modification of the form of spirometer employed in the universal respiration apparatus, the two chief differences being (1) the recessed part which contains the mechanical blower and (2) the unusual length of the bell. The first provides space for the blower without intricate connections and absolutely precludes leaks. It is a feature of the apparatus that has proved especially satisfactory in practice. The bell is made of sufficient size to allow not only for a full excursion if a deep breath is taken, but also for a considerable contraction in total volume of the air in the ventilating circuit as the oxygen is consumed.

To minimize the labor of breathing, the bell is delicately counterpoised by a weight (see *X*, figure 3) on the end of a silk cord running over a light aluminum pulley, *Z*, at the top. A pointer attached to the counterpoise shows, on a millimeter scale, the fluctuations in the height of the bell. To indicate accurately the somewhat large temperature changes a light-weight thermometer,[1] *T*, is inserted permanently in the top of the bell. To avoid getting water on the blower and consequent electrical damage, with danger of setting fire to the insulation in the oxygen-rich atmosphere, the water level in the spirometer should be considerably lowered when the apparatus is to be moved on an uneven floor.

ADJUSTMENT TO SUBJECT.

Almost universal adjustment of the mouthpiece is possible by means of the two hand wheels, *A* and *B*. (See fig. 2.) The former controls the movement of the 3-way valve and mouthpiece around the extension arm, *L*, as an axis, and also their location on the extension arm, while *B* permits raising or lowering the arm *L* on an upright standard, *S*. The extension arm can also be swung about *S* within the scope of the two rubber tubes, *W* and *G*. With no further adjustment the arm *L* may be placed in position for a subject either lying in bed or sitting in a

[1] At present a small Fahrenheit thermometer is used, as a centigrade instrument of like weight and temperature range is not available.

chair. When used for experiments with the subject in the standing position, the base is mounted on a wooden box of the desired height.

BREATHING APPLIANCES.

For the sake of simplicity in this description of the portable respiration apparatus, and since it was regularly used in all our experiments, the mouthpiece only is referred to and shown in the diagram, but we have reason to believe that the original form of inflated nosepiece used in the Nutrition Laboratory may be of even greater practical value, inasmuch as it has less influence upon the type of respiration.[1]

At first sight the use of a mask in a closed-circuit apparatus of this type would seem impracticable, as the slightest leak between the mask and the face would have a pronounced effect upon the measurement of the oxygen. Actual experience with the mask in the Nutrition Laboratory has, however, given good results. This form of breathing appliance is much more comfortable for subjects, permitting as it does free nose and mouth breathing, without the objectionable features of the mouthpiece.

AIR-MOISTENER.

Since with any type of breathing appliance the purified air passing along the tube is too dry to be breathed comfortably by the subject, a small moistening device, consisting of a wire-gauze frame covered with linen and thoroughly drenched with water, is inserted in the connection between the mouthpiece or other breathing appliance used and the circulating air.[2]

OXYGEN SUPPLY.

If the whole apparatus is filled with air at the beginning of a period, the percentage of oxygen in the confined air being breathed will fall considerably and might easily reach the point at which oxygen-want would be felt. Consequently, since the spirometer is of generous size, and it has been established by Higgins[3] that the respiration of oxygen-rich atmospheres is without effect upon the gaseous metabolism, a liberal supply of pure oxygen from a cylinder is introduced into the system prior to connecting the mouthpiece with the subject and after an equivalent volume of air has been expelled through the 3-way valve. During the experiment the volume of air in the spirometer is decreased by approximately 250 c.c. per minute, or 2.5 liters in a 10-minute period. A rough calculation will indicate the probable amount of pure oxygen to introduce. In the course of an experiment there is an exchange of oxygen for nitrogen in the lungs and blood, so that the air in the system contains a little more nitrogen than at first, but repeated tests have

[1] For a full description of these nosepieces, also method of use, see Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, pp. 22–23.

[2] All workers in gaseous metabolism should refer to the monograph by Dr. T. M. Carpenter (Carnegie Inst. Wash. Pub. No. 216, 1915) for detailed description of respiratory apparatus of practically all the current types, with special reference on pp. 23, 36, and 37 to mouthpiece, nosepieces, and moistening device.

[3] Benedict and Higgins, Am. Journ. Physiol., 1911, 28, p. 1.

shown that the percentage of oxygen in the residual air at the end of a 10-minute or even 15-minute experiment is always very considerably above that of the oxygen in outdoor air. Consequently subjects can never suffer from oxygen-want.

EXPERIMENTAL PROCEDURE.

The use of the apparatus should be preceded each day by a test for tightness which is easily made by placing a 100-gram weight on top of the spirometer. If there is a leak at any point the spirometer will show it definitely in 3 minutes. After the weight is removed, the motor is started and approximately 2.5 liters of pure oxygen admitted from the cylinder through the pet-cock, *P* (fig. 3). As each millimeter on the scale corresponds to approximately 21 c.c. (the exact value is determined at the time of construction),[1] this amount of oxygen is sufficient to raise the bell approximately 120 mm. The oxygen is best introduced when the spirometer bell is about one-third of the distance above its lowest level, as this allows for exaggerated expiration or inspiration without completely filling or emptying the spirometer.

Since the apparatus is primarily designed for measuring oxygen only, for the time being we need not consider the method of measuring the carbon dioxide. The connection of the subject with the air circuit is controlled by the 3-way valve (see *V*, fig. 2), which may be opened directly to the room air or, by turning it 90 degrees, connected with the ventilating air circuit. A small double-headed arrow, stamped on the top of the valve, indicates in which direction it should be turned. The opening to the room air usually points down and is not shown in figure 2. A short elbow is attached to this opening and over the end of the elbow a small piece of goose-down is fastened with a bit of wax. The movements of this feather indicate the respiration rate and the end of each expiration.

With the breathing appliance attached, the subject is first allowed to breathe room air through the side opening of the 3-way valve. The temperature of the spirometer bell and the position of the pointer on the scale are recorded, also the barometer,[2] which should be read to the nearest millimeter. As soon as the respiration appears normal, the 3-way valve is quickly turned 90 degrees to connect the subject with the air current. This should be done at the end of a normal (not forced) expiration. At the moment of turning the valve, the exact time is noted, preferably with a stop-watch. Practically no further attention need be given to the subject or apparatus until the end of the experiment. It is preferable to have the subject keep awake during the experimental period and we frequently find it necessary to tap on the air-pipe to make sure that he has not fallen asleep. At the end of 10 or

[1] Seven bells made on the same form gave by actual calibration the following values per millimeter: 20.99, 20.97, 20.86, 20.86, 20.83, 20.97, and 20.97 c.c., with an average of 20.92 c.c.

[2] A good aneroid barometer reading in millimeters is satisfactory, as an error of 7 or 8 mm. introduces an error of but 1 per cent in the final calculations.

12 minutes, the excursions of the bell are carefully watched and at the conclusion of a normal expiration the 3-way valve is again turned, disconnecting the subject from the ventilating air current; the time is then noted. The mouthpiece and nose clips are removed, and the subject lies quietly until another period is begun.

It is a fundamental rule in this Laboratory that all subjects, prior to measurements of the gaseous metabolism, must be lying down, resting quietly for not less than 30 minutes. The length of time between periods need be determined only by the activity of the operator in recording his observations. After the end of the period 1 minute is allowed to elapse to insure a thorough mixing of the air and removal of carbon dioxide. When the pointer indicates that the level of the spirometer is constant, this is read and the temperature is recorded.

MODIFIED METHOD FOR DETERMINING THE OXYGEN CONSUMPTION.

In testing several of these apparatus, Mr. Louis E. Emmes, of the Laboratory staff, has had excellent success in determining the oxygen consumption by using a modification of the method outlined in that he reads the spirometer *after* the subject has been connected with the air current. Noting the height to which the spirometer is raised at the end of a series of regular normal expirations, he starts a stop-watch. The experimental period then continues about 12 minutes, when again the height of the spirometer at the end of a series of 3 or 4 normal expirations is noted and recorded, and simultaneously the watch is stopped. Using the difference between the two readings as an index of the oxygen consumption, the usual calculations for temperature and pressure are then applied.

The obvious advantage of the Emmes method lies in the fact that while the goose feather over the opening in the 3-way valve gives a fair indication of the end of a normal expiration for determining the moment to begin the experimental period, this point is much better indicated by the actual excursions of the spirometer bell. Mr. Emmes thus uses the excursions of the bell to begin as well as to end the period. The two methods may be simultaneously applied and one period be made to include another. This involves only two additional readings of the height of the spirometer bell and two additional time records with a second stop-watch. The use of the modified method is recommended in all cases as a desirable check. A series of tests shows that a somewhat better agreement of duplicate periods may be secured with the Emmes method.

A still further check may be obtained by making the usual records before and after the valves are turned at the beginning and end of the period, and employing the Emmes method for two additional readings 10 or 20 seconds apart at the beginning of the period after the subject has been connected with the air current and again before he is disconnected at the end of the period. Two stop-watches are used for these intermediate records. Thus two sets of readings are secured for con-

trol within one 12 to 13 minute period, and in one 15-minute period it is possible to secure readings for three determinations of the oxygen consumption.

At the conclusion of a period, oxygen is again admitted, the initial position of the spirometer read, connections made with the subject as before, and a new period begun. All of this can be carried out without stopping the motor. If, during the first period, a larger amount of oxygen has been introduced than is actually consumed, a little more air can be rejected by turning the 3-way valve and lifting slightly the counterpoise. It is thus seen that the oxygen consumption may be approximately measured by the fall of the spirometer and the actual computation of this contraction in volume be completed by using the data obtained regarding the temperature and barometric pressure.

METHOD OF CALCULATING OXYGEN CONSUMPTION.

The method of calculating the amount of oxygen consumed in one period of an actual experiment may be illustrated by period 1 of the experiment with *Bro* on January 8, 1918. (See table 3.) In the two earlier periods of this experiment, the mask was employed; in this period the mouthpiece was used, and two sets of records were made, one being included in the other. The intermediate measurement[1] is designated for convenience "period *1a*."

TABLE 3.—*Calculation of oxygen consumption in experiment with the portable respiration apparatus.*

Subject: *Bro*. Date of experiment, Jan. 8, 1918.
Apparatus used: Portable respiration apparatus No. 1. Breathing appliance: Mouthpiece.
No. of period: 1, *1a*. Duration period 1....... 15′16″ (15.27′)
Period 1 began 6 a. m. Duration period *1a*...... 8′ 8″ (8.13′)

Height of spirometer bell.

	Period 1.	Period *1a*.
Beginning	984 mm.	942 mm.
End	820 mm.	853 mm.
Difference	164 mm.	89 mm.

Temperature of spirometer.

	Period 1.	Period *1a*.
Beginning	75	78
End	82	80
Av. (°F.)	78.5	79
Av. (°C.)	25.8	26.1

Barometer 740.6 mm.

	Logarithms. Period 1.	*Logarithms.* Period *1a*.
Difference in height of spirometer bell	2.21484	1.94939
Volume per mm. height of spirometer bell	1.32056	1.32056
To reduce to 0° C.	9.96071–10	9.96027–10
To convert to 760 mm. pressure	9.98877–10	9.98877–10
Decrease in volume at 0° C. and 760 mm. (oxygen consumed)	3.48488	3.21899
Duration of period	1.18384	0.91009
Oxygen consumed per minute	2.30104 =200c.c.	2.30890 =204c.c.
Correction for reduction of total vol. of air to 0° C. and 760 mm. (+1 c.c. for each rise of 1° F.)	+7	+2
	207c.c.	206c.c
Average of two measurements of oxygen consumed per minute	207 c.c.	

[1] In this case but one intermediate period instead of two was recorded.

The apparatus and breathing appliance used, the date, and the num ber of the experimental period are first recorded, also the subject's name. The times of beginning and ending the experiment are likewise recorded, that is, the exact moment the valve is turned connecting or disconnecting the subject with the air-current. The duration of the two measurements of oxygen are given, the figures in parentheses showing these times with the seconds reduced to decimals for convenience in calculating.

In the middle section records are made of the height of the spirometer bell and the temperature of the spirometer (°F.) at the beginning and end of the complete period and the intermediate period. From these records the average temperature (centigrade) of the spirometer and change in height of the spirometer bell are calculated for the two measurements.

In the lower section the cubic centimeters of oxygen per minute are computed by logarithms. The decrease in the volume of air is first calculated from the difference in height of the spirometer bell by means of the factor for this spirometer (20.92 c.c. for each millimeter of change), then reduced to 0° C. and 760 mm. pressure, using the average temperature of the spirometer during the measurements and the barometer record obtained for the period. Thus the logarithm of the spirometer difference for the total period (164 mm.) is 2.21484; the number of cubic centimeters represented by each millimeter of difference for this spirometer is 20.92, with a logarithm of 1.32056. The logarithm for the factor used to reduce the average temperature of the spirometer to 0° C. (9.96071 − 10) and that for the factor to reduce the observed pressure to 760 mm. (9.98877 − 10) are also found from tables prepared for the purpose. The total of the four logarithms gives the logarithm (3.48488) for the decrease in volume of the air in the apparatus during the period, at 0° C. and 760 mm. pressure, this being equivalent to the volume of oxygen consumed. No correction is made in this calculation for the tension of aqueous vapor, as it is assumed that the air as measured is dry.[1] From the logarithm of this volume is subtracted the logarithm 1.18384 for the duration of the measurement (15′ 16″), the result giving the logarithm for the cubic centimeters of oxygen consumed per minute, in this case 200 c.c.

A further correction in the results obtained by this method of calculating is necessary, inasmuch as the total volume of air in the spirometer and air system should be reduced to 0° C. and 760 mm. pressure at the beginning and end of the period to obtain the true shrinkage in the

[1] For the measurement of the total period, this assumption is correct. During the measurements in the intermediate period (*a*) made by the Emmes method, there is unquestionably a certain amount of moisture in the air. Theoretically corrections should be made for this moisture. It has been shown, however, by means of a sensitive psychrometer placed in the air-circuit, that the percentage of moisture is so small that in practice it may be neglected in the calculation of the oxygen consumption during these short periods.

volume of air. Such computations have been made for 14 experiments in which from 198 to 272 c.c. of oxygen were used and with temperature fluctuations ranging from 3° to 19° F. It was found that the difference as a result of making this reduction corresponds to +1 c.c. of oxygen for each degree Fahrenheit of the rise in temperature during the measurement. It is therefore justifiable, for the sake of simplicity, to make an arbitrary correction by adding 1 c.c. of oxygen for each degree of the rise in temperature of 7° F. This gives a value of 207 c.c. of oxygen per minute consumed during the period of 15 minutes and 16 seconds.

The same method is followed in calculating the oxygen consumed during the intermediate measurement, *i. e.*, period *1a*. The agreement of the two measurements is excellent, 207 and 206 c. c. oxygen per minute.

PRACTICAL USE OF THE APPARATUS.

From the foregoing description it will be seen that this apparatus dispenses with gas analysis and weighings. By reading the millimeter scale indicating the height of the spirometer bell, the thermometer in the top of the spirometer, and the barometer, we may obtain all the data required for rapidly computing oxygen consumption and heat production. The apparatus is designed particularly for the determination of the oxygen consumption, with special reference to clinical application. It can not be used for the determination of the respiratory quotient as a substitute for either the respiratory-valve method outlined by Dr. Carpenter (a closely fitting mask, Tissot valves, a carefully calibrated spirometer, good gas-analysis apparatus, and a good gas analyst) or the perfected form of the clinical respiration apparatus developed in the Nutrition Laboratory.[1] The portable respiration apparatus has, however, the advantages of portability, simplicity, and rapidity of operation, with a degree of accuracy in the determination of the oxygen consumption to meet the needs of practically all scientific work. It was particularly adapted for use in the low-diet research for simultaneously measuring the basal metabolism of seven young men each morning. Four of the apparatus employed for these observations are shown in figure 4 in position, with accompanying beds, in one of the laboratory rooms at the Young Men's Christian Association College, Springfield, Massachusetts.

GROUP RESPIRATION APPARATUS.

While the universal respiration apparatus in its various forms permits the measurement of the metabolism of an individual, even when he is working to the limit of human endurance, it is practically limited to the measurement of a carbon-dioxide production not exceeding 2,700 to 2,800 c.c. per minute. As a matter of fact, this particular

[1] Benedict and Tompkins, Boston Med. and Surg. Journ., 1916, **174**, pp. 857, 898, and 939.

FIG. 4.—Portable respiration apparatus ready for bedside use with four subjects at the International Young Men's Christian Association College, Springfield, Massachusetts.

FIG. 5.—Interior of group respiration chamber showing arrangement of beds [illegible] of 4 each. Glass jars for night urines.

intensity of metabolism has been accurately measured with the universal respiration apparatus, both by Cathcart[1] and by Murschhauser.[2] The measurements are, however, confined to those for one person and no attempt has been made to utilize the apparatus in connection with a large respiration chamber.

A larger apparatus, based on essentially the same principle as the universal respiration apparatus, was used with a respiration chamber in the chemical laboratory at Wesleyan University, Middletown, Connecticut, for studying the carbon-dioxide output during the severe muscular work of bicycle riding. With the universal respiration apparatus the periods must be limited to 10 or 15 minutes. With the respiration chamber at Wesleyan University periods as long as 1 or 2 hours could be used. With this apparatus all of the carbon dioxide produced was absorbed from the ventilating air current by soda-lime, thus calling for literally enormous amounts of soda-lime. As a matter of fact, three large soda-lime cans in series were required to absorb the 200 or more grams of carbon dioxide produced in one hour.[3] Since these earlier experiments were for only a few hours, this particular proceeding was neither too time-consuming nor too expensive, but if a research were undertaken in which a large amount of carbon dioxide was produced over a considerable period of time, the question not only of the expense but of the mere matter of providing sufficient soda-lime would be a very serious one.

With the universal respiration apparatus it would be easy to develop two independent sets of absorbing systems and shift from one to the other at the end of every 15 to 20 minutes, but even then the mechanism would not permit the absorption at a maximum of more than 3,000 c.c. per minute. Consequently, for a research involving the simultaneous measurement of the carbon-dioxide production of a number of individuals, such as in group experiments, this particular type of apparatus would not suffice.

The Nutrition Laboratory has long recognized the need of a large chamber in which not only a group of individuals could be studied simultaneously but two, three, or more individuals could be made to perform intense muscular work and their carbon-dioxide production during the activity accurately measured. Precisely this type of problem presents itself to all workers in animal nutrition, for the carbon-dioxide production with large domestic animals is so great as to demand extremely costly and elaborate apparatus, such as the marvelous installation of Professor H. P. Armsby[4] of State College, Pennsylvania. While the Nutrition Laboratory is not engaged in research with large

[1] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913.
[2] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915.
[3] Benedict and Carpenter, U. S. Dept. Agr., Office Expt. Sta. Bul. 208, 1909, p. 31.
[4] Armsby and Fries, U. S. Dept. Agr., Bur. Animal Industry, Bul. 51, 1903; and Experiment Station Record, 1903–1904, **15**, p. 1037.

domestic animals,[1] it has in the immediate future the problem of studying the metabolism of large wild animals, in connection with its investigations in progress at the New York Zoological Park. It also had the immediate problem in the reduced ration research of studying the metabolism of a group of individuals. Thus the need of a large chamber was urgent.

In the original architectural plan of the Nutrition Laboratory the calorimeter room was tentatively subdivided to provide for several respiration calorimeters, and space was left for the construction of a large respiration calorimeter for studying the metabolism of groups of individuals. Nearly a decade passed before it was practicable to build an apparatus of any type in this space. During that time sufficient experimental evidence had accumulated to show that direct calorimetry on a large group of this kind would not only be very expensive but also time-consuming. It was therefore considered that our experience with indirect calorimetry fully justified the construction of a respiration chamber without calorimetric features.

The only chamber of this type which has been used for the study of the metabolism of a number of individuals at one and the same time is that formerly employed in Stockholm and constructed by Sondén and Tigerstedt,[2] but now demolished and subsequently duplicated in Helsingfors by Professor Tigerstedt.[3] The Sondén-Tigerstedt chamber had a capacity of 100 cubic meters and the carbon dioxide alone was determined. According to their method of determination a rather complicated meter, with blower system for ventilation, was required, an elaborate aliquoting device for the storage of samples of air from the chamber in 1-liter mercury containers, and finally, a very delicate and fragile and for Americans, at least, almost inaccessible form of gas-analysis apparatus, namely, the Sondén-Pettersson[4] gas-analysis apparatus for carbon dioxide.

The Nutrition Laboratory has already carried out an extensive research with one of the ingenious gas-analysis apparatus of Sondén.[5] This apparatus, which is designed primarily for studying the composition of outdoor air, permits the determination of carbon dioxide to three significant figures, that is, to 0.001 per cent. An accuracy of 0.001 per cent is possible in determining oxygen. The particular form of Sondén-Pettersson apparatus used by Sondén and Tigerstedt was designed especially for the determination of carbon dioxide only and an

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[1] Since this was written, such a research has been begun by the Nutrition Laboratory, at the Agricultural Experiment-Station, Durham, New Hampshire.

[2] Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, **6**, p. 1.

[3] Tigerstedt, Skand. Arch. f. Physiol., 1906, **18**, p. 298.

[4] Pettersson, Zeitschr. f. anal. Chem., 1886, **25**, pp. 467 and 469; Pettersson and Palmquist, Ber. d. deutsch. chem. Gesellsch., 1887, **20**, p. 2129; Sondén, Zeitschr. f. Instrumentenkunde, 1889, **9**, p. 472.

[5] Benedict, Carnegie Inst. Wash. Pub. No. 166, 1912.

even greater degree of accuracy was possible. Indeed, with their apparatus it was possible to determine the carbon dioxide with an accuracy of 0.0001 per cent. This extraordinary accuracy made it possible for the Stockholm investigators to utilize their large respiration chamber for studying the metabolism of a single individual in complete muscular repose. It is obvious, however, that an apparatus of this type requires an especially capable gas analyst.

The dimensions of the Stockholm and Helsingfors chambers seemed to us much too large for ordinary observations on groups of individuals or with severe muscular work. It was therefore considered that in building the group chamber for the Nutrition Laboratory it would be advantageous to minimize the volume in so far as would be consistent with flexibility in adapting it to the types of experiment desired. Accordingly, a chamber with approximately one-half the volume of the Helsingfors chamber was constructed.

The first research in which the group respiration apparatus was employed was one which has been in progress for a year or more in cooperation with Simmons College, namely, the study with a group of young women of college age of both the resting requirements and the carbon-dioxide production during various domestic activities. The original intention was to describe this apparatus in detail in the published report of the research with the Simmons College students. The exigencies of the situation, however, demand that a somewhat lengthy description should be given here of the technical apparatus used for a considerable number of observations in this research on under-nutrition.

The entire apparatus has been built by the construction staff of the Nutrition Laboratory. To Mr. W. E. Collins and his assistant, Mr. F. A. Renshaw, our appreciation is here expressed for the skilful way in which the apparatus was constructed.

GENERAL PRINCIPLE OF GROUP RESPIRATION APPARATUS.

The respiration chamber is of air-tight construction and supplied with a current of outdoor air by means of a rotary air-impeller. At a diametrically opposite corner of the chamber from this air-impeller is a pipe which conducts the air to a second rotary air-impeller of the same type and size. By means of a simple system of butterfly valves the absolute amount of air passing through the chamber can be adjusted at will. The air leaving the chamber is aliquoted by a method developed for this apparatus. A large portion of air is discharged freely into the laboratory room and two smaller portions, alike in amount, are discharged under special conditions into containers from which the air is withdrawn as desired. The air sample may be analyzed by volumetric analysis or, as is actually done in this case, the carbon dioxide may be removed by passing the air through soda lime.

RESPIRATION CHAMBER.

Personal visits to Stockholm and Helsingfors and inspection of both the Scandinavian chambers led to material modification in the design for the chamber built in the Nutrition Laboratory. Thus it was seen that the height could easily be reduced. Second, the entrance to the chamber was best made from the top; fortunately the unusually high ceiling of the calorimeter laboratory made this change possible without difficulty. The calorimeter laboratory is provided with excellent automatic heating and cooling arrangements for maintaining uniform temperature. Hence no special appliances for heating the new respiration chamber were needed. As a matter of fact, it was found subsequently that cooling rather than heating was absolutely essential.

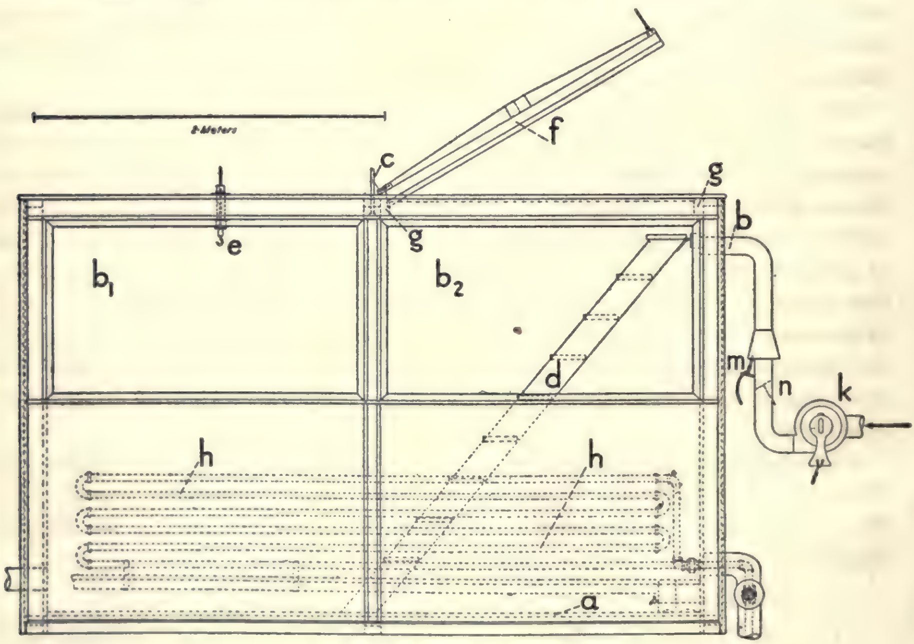

FIG. 6.—View of east end of group respiration chamber.

a, Inner wooden floor; b_1 and b_2, windows; *c*, suspension-rod supporting roof of chamber; *d*, step-ladder; *e*, hook for supporting ladder *d* when not in use; *f*, trap-door resting in groove *gg* when closed; *hh*, brine coil; *k*, rotary air impeller; *b*, opening into chamber for ingoing air; *m*, Bunsen burner for heating ingoing air; *n*, butterfly valve.

The details of construction of the respiration chamber are given in figures 6 and 7. Figure 6 shows the window (east) end of the chamber. A cross-section of the chamber in the longest dimension from west to east is represented in figure 7.

The respiration chamber has an inner lining of sheet metal, which is absolutely air-tight. As this inner lining required a substantial wooden backing to prevent unnecessary wear or play by the buckling of the sheet metal, a framework was built on the floor of the calorimeter room

from timber 4 inches square; this framework had a width of approximately 13 feet $3\frac{1}{2}$ inches and a length of 17 feet $9\frac{1}{2}$ inches. To this base were fastened the several uprights which were covered with a sheathing of $\frac{3}{4}$-inch matched lumber. The framework on the floor was then lined with galvanized iron, which extended up 10 inches on the wooden walls of the chamber, for it was believed that the greatest stress and wear would be borne by these parts. The rest of the inner metal lining was made from tinned sheet iron. The inner metal lining of the chamber has therefore a length of 17 feet, a width of $12\frac{1}{2}$ feet, and a height of $7\frac{1}{2}$ feet. The outside of the chamber was finished with $\frac{1}{8}$-inch "compo board," which was painted. Between the compo board and the inner wooden wall is an air-space of 4 inches.

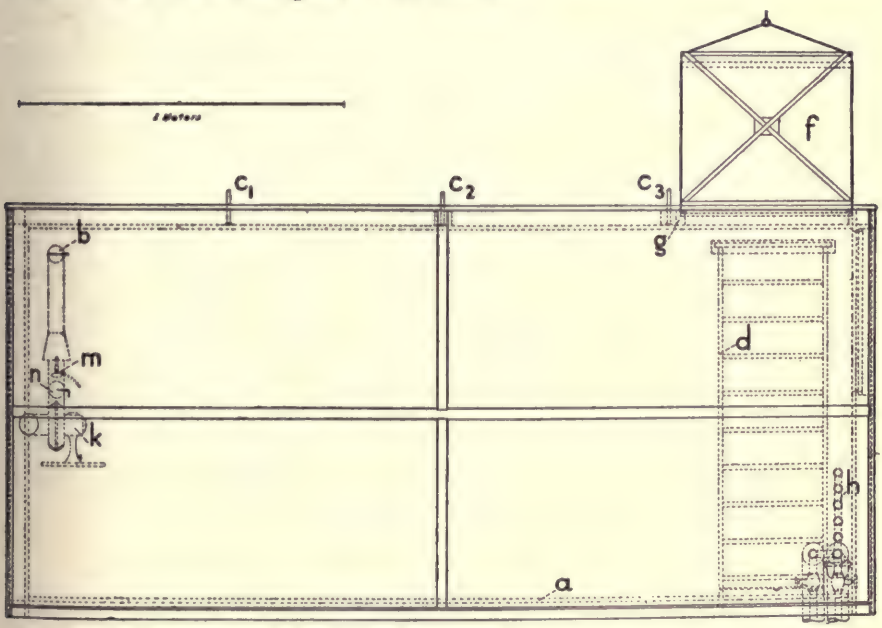

Fig. 7.—Cross-section of group respiration chamber from west to east.

a, Inner wooden floor; *b*, opening for ingoing air; c_1, c_2, and c_3, $\frac{3}{4}$-inch suspension-rods; *d*, step-ladder; *f*, trap-door; *g*, water-seal trough; *h*, brine coils; *k*, rotary air-impeller; *m*, Bunsen burner for heating ingoing air; *n*, butterfly valve.

To prevent excessive wear of the galvanized iron floor, it was necessary to install an inner wooden floor (*a* in figs. 6 and 7), which was made of $\frac{7}{8}$-inch maple flooring, resting upon 2 by 4 inch wooden stringers, laid on edge. This floor was substantially made and well smoothed to secure a rigid base upon which groups of individuals could walk with freedom or perform severe muscular exercise. The original intention was to have the floor as nearly as possible air-tight, so as to consider as the flexible or movable portion of air inside the chamber only that above the floor. For this purpose a copper flashing was soldered to the bottom of the metal wall, turned in over the top of the maple flooring, securely tacked to the floor and filled in with shellac.

Although thoroughly seasoned maple was used for the floor, in a very short time there was sufficient shrinkage to cause extensive diffusion of air through the slight openings. It thus became necessary to include the air in the space under the floor in the total air volume of the chamber. A series of 1-inch holes were bored along the north and south edges of the floor near the walls, to facilitate free passage of air.

In the east end of the chamber are two large sheets of plate glass, 5 feet 10 inches by 39 inches (b^1 and b^2, fig. 6), set into rigid frames which terminate in the sheet metal interior wall. Both sheets of glass are well imbedded in a large amount of physicist's wax, which is then covered with shellac. These windows provide full illumination for the chamber, as there is but a 2-foot passage between them and the large double window on the outside wall of the calorimeter laboratory. Consequently it has never been necessary to use artificial illumination.

The roof of the chamber is suspended by three $\frac{3}{4}$-inch iron rods (c^1, c^2, c^3, fig. 7) attached to the structural steel beams in the ceiling of the calorimeter room laboratory. This construction is so rigid that a dozen men can walk at any place on the roof of the chamber without causing a perceptible sag.

The entrance to the chamber is in the northeast corner of the roof. A stout step-ladder, *d*, one end of which is attached to the wall permanently, leads down into the chamber. When desired, this ladder can be hooked up out of the way (see *e*), a counterpoise rope assisting in its elevation. The corners of the trap door, *f*, are made of strong sheet copper, reenforced with a wooden framework. This door is likewise counterpoised by a window-weight and cord running over two pulleys. When the door is lowered, the edge (which is $3\frac{1}{4}$ inches deep) fits into a trough, *g*, surrounding the opening into the chamber. This trough is approximately one-half to two-thirds filled with water, thus supplying a complete seal and perfect freedom in opening and closing.

In the east end of the respiration chamber is a brine coil, *h*, connected with the refrigerating brine service of the Harvard Medical School power-house. By opening the valves an unlimited amount of cold brine may be passed through this coil, and the heat generated by the subjects inside the chamber brought away rapidly. To hasten or facilitate this withdrawal of heat the electric fan, which is always placed inside the chamber to insure uniform mixture of air, may be so turned as to deflect the air against the brine pipes. The temperature of the room can be easily controlled by this method.

The special features to be emphasized in connection with this respiration chamber are: (1) it is absolutely air-tight; (2) it provides an air-tight and easily opened and closed entrance by means of a trap-door and water-seal; (3) the glass windows at one end provide complete illumination; (4) provision for cooling is made with the brine coil.

As may be seen, the respiration chamber has relatively few new features. Indeed, any type of air-tight chamber providing entrance may be employed, but this particular type of construction seemed to us best suited for the special purpose of the Nutrition Laboratory. As will be shown later, the shape and size of the chamber play a relatively small rôle. The entrance may be changed to one end of the chamber, if desired; and for experiments with large wild or domestic animals, such a change in location would be practically necessary. Heat may be brought away without using a brine coil if the chamber is perfectly air-tight and some adequate system of cooling is used, such as exposing the metal walls to the free circulation of indoor air, rather than, as here shown, protecting them by sheathing, dead-air space, and finally compo board. The essentially novel feature of the whole installation is the maintenance, aliquoting, and analyzing of the ventilating air-circuit.

VENTILATION OF RESPIRATION CHAMBER.

As may be noted in figure 6, air is taken from outdoors and delivered by means of a rotary air-impeller, *k*, through an opening, *b*, near the top of the chamber. Since on many days in winter the outdoor air is extremely cold, it has been necessary at times to warm the air. This is done by means of a Bunsen burner, *m*, with a small hood, attached to the outside of the sheet metal pipe carrying the air from the blower to the chamber. By regulating the size of this flame, any degree of temperature may be secured for the air entering the chamber. Butterfly valves, *n*, in the air-pipe control the amount of air delivered to the chamber and may be adjusted at will, irrespective of the speed of the blower. For practically all experiments thus far made we have used only a fraction of the possible discharge from the blower and the cross section of the pipe has always been considerably reduced by turning the butterfly valve.

INCOMING AIR.

The incoming air is taken from a point outside the north window of the building. The pipe on the intake side of the blower enters the calorimeter laboratory through a board fitted into one of the windows and has a diameter of 6 inches. The pipe between the blower and the chamber has a somewhat smaller diameter, 4 inches. No provision is made for noting directly the amount of air entering the chamber or its degree of humidity. In fact, as will be seen later, no analysis is made of the ingoing air. This is one of the simplified features of the apparatus. Care is taken to deliver to the chamber only uncontaminated outside air. Repeated analyses of air in the neighborhood of the Nutrition Laboratory have shown that, for all practical purposes, the carbon-dioxide content is constant, irrespective of weather conditions, temperature, or season.[1]

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[1] Benedict, Carnegie Inst. Wash. Pub. No. 166, 1912, p. 114.

OUTGOING AIR.

From the experience of more than a decade with the ventilation of various types of respiration chambers, it was clear that a provision for the rapid renewal of air inside the chamber was unnecessary. Experiments at Wesleyan University for periods of 2 to 13 days have shown that if the ventilation is sufficient to maintain the carbon-dioxide content of the air inside the chamber at not more than from 0.5 to 1 per cent, no discomfort is experienced by human subjects. Indeed, in one instance a human subject lived in an atmosphere containing approximately 2 per cent of carbon dioxide for more than 24 hours without discomfort. Without doubt the greatest factors in determining so-called "bad" air are temperature and humidity; we firmly believe that carbon dioxide, *per se*, has no influence.

Until the oxygen content is lowered to considerably below 15 per cent there is no evidence of labored respiration or indication of oxygen-want. On the other hand, since moisture in the air and especially a high temperature are extremely disagreeable, it became necessary to remove the moisture by a sufficient flow of air in the chamber or to condense it by use of brine, which likewise provided for temperature control. Finally, we decided that the safest procedure would be to adjust the rate of ventilation so that the percentage of carbon dioxide residual in the air in the chamber would be not far from 0.5 per cent, and to control the total amount of the ventilating air-current so that this adjustment could be made within wide limits. In other words, when but a small amount of carbon dioxide is being produced, the total ventilation would be low; when a large amount, it would be very high. This fluctuation in the possible ventilating capacity of the chamber was readily secured by the use of the rotary air-impeller, referred to in a foregoing paragraph. These impellers, the discharge of which may be cut down at will by butterfly valves, permit the movement of a very large amount of air through the chamber in a very short time. Indeed, with the impeller used here, with a discharge of 97 mm. and with a speed of the armature shaft of 1,700 revolutions per minute, it has been computed that the entire volume of the chamber can be swept out in a very few minutes with full and free discharge of the blowers. On the other hand, by reducing the delivery by butterfly valves or other suitable device, the total ventilation of the chamber can be brought to as small a volume as desired.

It is thus apparent that the carbon-dioxide content of the outcoming air will, under all circumstances, be very considerably greater than that of normal air; hence the problem of measuring exactly the total carbon dioxide removed from the chamber assumes grave importance. To pass the entire air-current through soda-lime would, for reasons outlined previously, be wholly impracticable, as it would require an absorption system of purifiers which would be difficult to maintain, a

very large amount of soda-lime, and provision for taking care of the intense heat of reaction between carbon dioxide and soda-lime. It became necessary, therefore, to provide for an accurate aliquoting of the main air-current leaving the chamber; this aliquoting device forms the chief feature in our description of the group respiration chamber.

ALIQUOTING AND ANALYSIS OF VENTILATING AIR-CURRENT.

On the general fundamental principle that the total ventilating air-current passing through the chamber should be of such a magnitude as to maintain a carbon-dioxide content in the air inside the chamber of not far from 0.5 per cent, several possible methods for the determination of the carbon dioxide in the outcoming air presented themselves. Thus, one could use the long-established method of Pettenkofer and Voit[1] of determining the carbon-dioxide content of both the incoming and outgoing air, noting the total amount of air leaving the chamber through a series of meters, and computing from these the carbon dioxide produced inside the chamber. This would require complicated gas analysis which, if possible, it is desirable to eliminate. Our success with the universal respiration apparatus and its train of purifiers, consisting of soda-lime bottles and sulphuric-acid bottles of the Williams type, naturally led to an attempt to employ this thoroughly-tested train in connection with the analysis of the air leaving the chamber.

GENERAL PRINCIPLE OF METHOD FOR ALIQUOTING AND ANALYSIS.

The apparatus as finally developed is based upon the following principle: First, the air leaving the chamber is delivered into a copper box or wind chest, provided with three circular openings. Two of these openings have diameters exactly alike. The other may be adjusted to size, either by an iris diaphragm or still more accurately with a series of metal disks with circular openings of definite, known size. The air leaving this wind chest escapes either into the room or into a vessel in which it may be collected. Since the free discharge from this wind chest is a prerequisite, some device must be attached to insure that the air passing through the two small openings will be discharged against atmospheric pressure. Furthermore, as the air leaving these small openings is to be used for sampling, the sampling cans into which the air is delivered should be provided with some means for removal of the air as rapidly as it is delivered, so as to insure atmospheric pressure in these cans.

Extended experience has shown that, as used with the universal respiration apparatus, the standard size soda-lime and Williams bottles are extraordinarily efficient in removing from an air-current both water vapor and carbon dioxide for long periods of time. These may be used for a ventilation as high as 100 liters per minute, as is done in

[1] Pettenkofer and Voit, Ann. d. Chem. u. Pharm., 1862, Supp. Bd. II, pp. 1 and 52.

the universal respiration apparatus when applied to muscular work experiments, but they are best used with a ventilation of approximately 45 to 50 liters per minute. Hence the orifice leading into the sampling cans was made of such size (10 mm. in diameter) as to allow the escape of approximately 45 to 50 liters of air per minute through it. Thus, by connecting to the sampling can a suction pipe leading to a positive blower run by an electric motor, air at the rate of 45 liters per minute could be withdrawn, passed through suitable purifiers, and the carbon dioxide in it collected in a soda-lime bottle, as is done with the universal respiration apparatus. The amount of carbon dioxide thus collected obviously represents the total amount in the sample.

Another factor in determining the size of the orifice leading into the sampling can and the total amount of air to be taken care of by the purifying device was that with these bottles, although the combined weight of one soda-lime and one sulphuric-acid bottle is approximately 5,500 grams, it is necessary, to minimize errors in weighing, that not less than 2.5 to 3 grams of carbon dioxide should be absorbed. With a ventilation of 45 liters per minute and the residual carbon dioxide 0.5 per cent, the amount absorbed would correspond to approximately 9 grams of carbon dioxide in a 20-minute period. Even if the ventilation were so adjusted as to have the carbon-dioxide content but 0.25 per cent, the amount absorbed would be approximately 4.5 grams for a period as short as 20 minutes. It is thus possible to use short periods with the respiration apparatus, provided the production of carbon dioxide is sufficient for the carbon-dioxide content of the residual air to be at least 0.25 per cent. Obviously, if the total ventilation of the group chamber could be reduced to but 45 liters per minute, the universal respiration apparatus itself would suffice for the absorption and measurement of the carbon dioxide in the air, and we would have here nothing but a magnified form of the clinical respiration chamber developed and in use in this laboratory.[1]

But since the use of our large respiration chamber, with a volume of 44,000 liters, involves a much greater production of carbon dioxide than the clinical respiration chamber, with a volume of but 600 liters, a ventilation of 45 liters per minute would be inadequate for the removal of the larger amount of carbon dioxide, because the ventilation of a respiration chamber is dependent upon two factors (1) the amount of carbon dioxide produced and (2) the percentage of residual carbon dioxide desired.

The main problems, therefore, in the aliquoting and analysis of this air-current, are, first, to secure perfect aliquoting, and, second, to insure constancy in both the amount and pressure conditions of the air discharged; finally, since the outdoor air entering the respiration chamber contains a definite percentage of carbon dioxide, the calculation of the

[1] Benedict and Tompkins, Boston Med. Surg. Journ., 1916, **174**, pp. 857, 898, and 939.

total amount involves a knowledge of the volume of air entering the chamber.

COLLECTION CHAMBERS AND ABSORPTION APPARATUS.

The collection chambers and absorption apparatus, as shown in figure 8, are mounted upon a substantial oak table which is provided with a lower shelf. At the extreme right on the shelf is the rotary air-impeller, *a*, directly connected with an electric motor, *t*. This discharges the air taken from the respiration chamber into a large copper

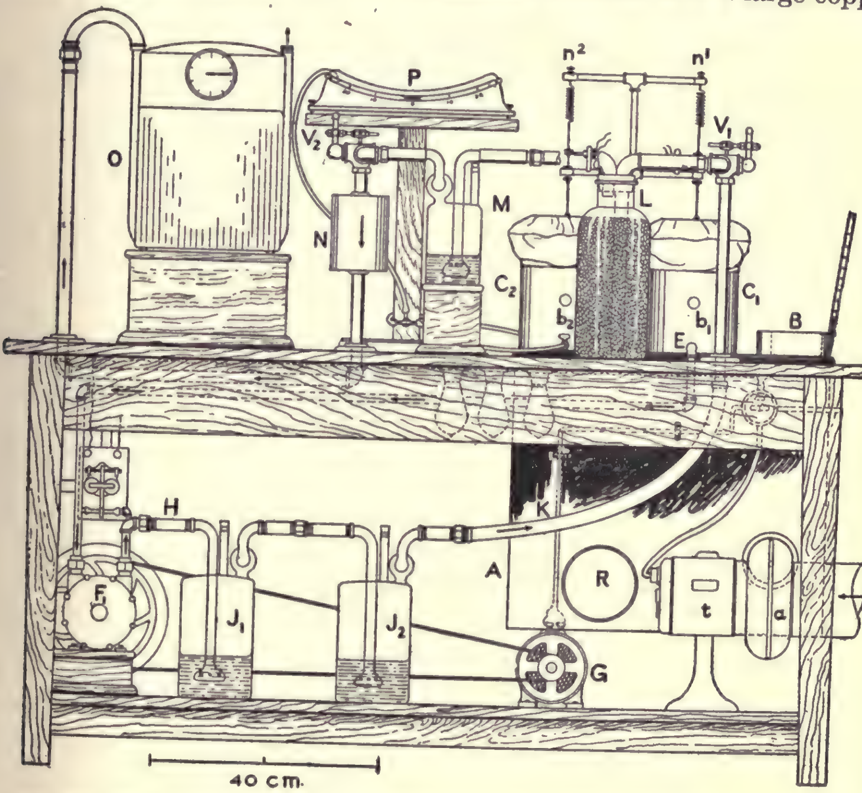

FIG. 8.—Side view of collection chambers and absorption apparatus of the group respiration chamber.

Air from the group chamber is delivered into the wind chest *A* by means of the rotary air-impeller *a*, driven by the electric motor *t*. The larger portion of the air is delivered into the open air through a circular opening in *B*. The remainder passes into the cylindrical copper cans C_1 and C_2. The air is drawn from C_1 through the pipe *E* by means of the blower F_1 driven by the electric motor *G*. From F_1 by means of the tube *H* the air passes through the sulphuric acid containers J_1 and J_2, then by the tube *K* through the 3-way valve V_1, soda-lime container *L*, sulphuric-acid container *M*, valve V_2, sodium-bicarbonate container *N*, and finally through the meter *O* into the open air; an exact duplicate arrangement (see figs. 11 and 12) provides for the removal of air from the cylindrical can C_2. b_1 and b_2 are openings closed by rubber stoppers. *P* is a delicate petroleum manometer for indicating the pressure in the cans C_1 and C_2. n_1 and n_2 are nuts for regulating height of bathing caps on tops of cans C_1 and C_2. Valves V_1 and V_2 provide for the deflection of air from C_1 into another set of absorbers like *L* and *M*. *R*, hand hole to wind chest *A*.

wind chest, A, shown in detail in figure 9. In the top of this wind chest are three openings. At the extreme right there is an opening, B, figure 9, provided with a water seal into which caps of various sizes can be set. The other two openings, each of 10 mm., lead directly into the center of the bottom of two cylindrical copper cans, C_1 and C_2. These openings were drilled in disks at the same time and hence are of exactly the same size, which was subsequently proved by most careful calipering. Each disk is attached with a threaded collar to a pipe in

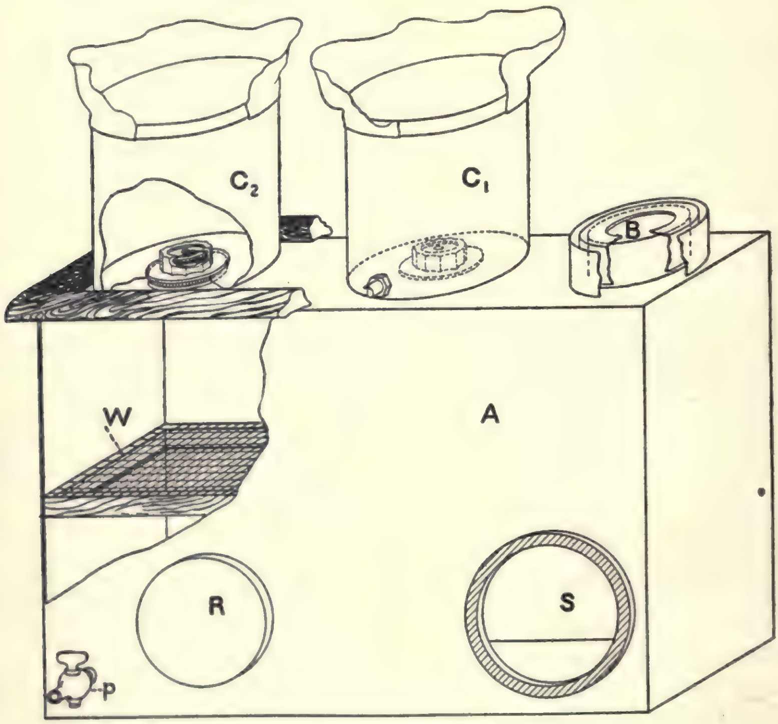

FIG. 9.—Detail of wind chest.

A, wind chest; B, opening to outside. C_1, C_2, cylindrical copper cans from which air is drawn by means of two Crowell blowers. R, hand hole; S, opening into wind chest for discharge from rotary air-impeller; W, wire screen; p, petcock for attaching manometer to obtain pressure in wind chest.

the top of the wind chest. Between the 10-mm. disks and this pipe are placed rubber gaskets, which insure tight closure. The details of this installation are given in figure 10, in which a is the brass disk with a 10-mm. orifice, b the collar, c the brass pipe soldered to the top of the wind chest, and d the rubber gasket. To attach the cans C_1 or C_2 to the top of the wind chest and secure an air-tight closure, a rubber gasket, e, is placed between the can and the wind chest and pressure applied by a threaded collar, f.

As will be seen from figure 8, each of the copper cans, C_1 and C_2, is provided with a flexible top consisting of a light weight, pure rubber, lady's bathing cap, which allows considerable flexibility in the volume of the can. Near the bottom of the can C_1 is a $\frac{3}{8}$-inch pipe (13 mm. inside diameter, see E, figure 8), which connects with the intake side of a Crowell blower, F_1. The blower is connected by a belt with an electric motor, G. The air discharged by the Crowell blower passes through the pipe, H, and is conducted through two Williams bottles, J_1 and J_2, containing sulphuric acid, in which the air is thoroughly dried. It then passes through a short length of hose, K, to a header on top of the table provided with a 3-way valve, V_1, by means of which the air may be deflected through a soda-lime can, L, and its accompanying Williams bottle, M. The soda-lime in L removes the carbon dioxide from the previously dried air-current and the sulphuric acid in M removes the water vapor imparted to the dry air-current by the somewhat moist soda-lime. The air, now freed from carbon dioxide and water vapor, enters another 3-way valve, V_2, and passes through a can,

a, brass disk with 10 mm. orifice; *b*, threaded collar; *c*, brass tube soldered to top of wind chest; *d*, rubber gasket; *e*, rubber gasket; *f*, threaded collar.

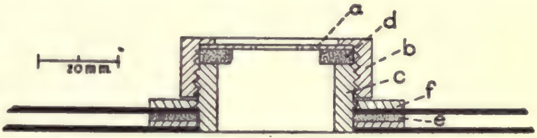

FIG. 10.—Detail of opening between wind chest (fig. 9) and can C_1 or C_2.

N, containing sodium bicarbonate which removes slight traces of acid fumes. Thence it passes through a pipe under the table to another header, is delivered directly into an ordinary form of dry gas meter, O, and is finally discharged into the room.

It is thus seen that by this system air coming from the respiration chamber is delivered by a rotary air-impeller into a wind chest and escapes through three openings, the largest being open to the air in the room and regulated in size by disks, and the other two leading into sampling cans with flexible rubber covers. The air delivered to the sampling cans is immediately drawn out through pipes to a Crowell positive blower which forces the air through a series of purifying vessels, *i. e.*, two sulphuric acid bottles for the complete removal of water-vapor, a soda-lime bottle for the removal of carbon dioxide, and finally a sulphuric-acid bottle for the absorption of the water vapor taken up in the passage of the air through the moist soda-lime. After being freed from any trace of acid fumes by passing through a chamber containing sodium bicarbonate, it is delivered into a dry gas meter which gives an accurate reading of the total volume of the sample.

Although the rotary air impeller, *a*, does not produce positive pressure in the sense that the positive blower, F_1, does, it obviously causes

a slight increase in the air tension inside the wind chest and the escape of air through the three orifices will be determined in large part by this pressure, which is tested by a manometer attached to the petcock (p), fig. 9, and is more or less roughly proportional to it. Tests have shown that with orifices of the same standard size, the amount of air delivered will vary directly in all cases with the pressure, although it may not necessarily be proportional to the pressure. It is of importance, however, to secure a condition whereby a sample of air delivered through a small orifice can be collected, withdrawn, and the carbon dioxide absorbed, and yet have the discharge through this small orifice under the same physical conditions, so far as pressure and tension are concerned, as the air passing through the large opening, B. In other words, the slight pressure inside the wind chest, due to the rotary air-impeller, renders it particularly necessary to make sure that on the discharge side of the three openings the pressure is always the same, *i. e.*, absolutely atmospheric.

To build a different type of wind chest for each aliquot was impracticable. It was accordingly arranged to make the large opening adjustable, using caps of various sizes to fit over the aperture. By this means the total amount of air leaving the wind chest is reduced and, incidentally, the amount of air discharged into the sampling cans through the 10-mm. openings is slightly modified by the slight increase in pressure inside the wind chest due to the fact that the free discharge is somewhat hindered by the reduction in size of the large aperture.

The maximum pressure inside the wind chest, even when all openings are closed, is, however, so small that relatively large variations in the amount of air leaving the wind chest influence but slightly the actual amount of air discharged into the separate cans. With the rotary air-impeller used and the 10-mm. openings, the amount of air discharged is reasonably constant at about 45 liters per minute, practically independent of the size of the main opening.

DUPLICATION OF SAMPLES.

With nearly all types of respiration apparatus, even those connected with chambers, the kind of experiment ordinarily employed is such that a repetition is usually easily made and with relatively slight expense, particularly with animals. On the other hand, when one proposes working with a large group of human individuals, to duplicate an experimental session is an expensive procedure; hence it was necessary at the outset to provide for duplicate analyses and duplicate samples. For this reason, two sampling cans were provided. The second can (C_2, fig. 8) is connected with an exact duplicate of the absorbing system in series with the can C_1. This second absorbing system has a separate Crowell blower (shown in the upper part of fig. 11 as F_2), its duplicate large Williams bottles for absorbing water vapor, and its

train of purifiers consisting of soda-lime bottle and small Williams bottle (see figs. 11 and 12). Thus both samples are taken at identically the same time.

In figure 8 but one soda-lime and one small Williams bottle are shown. As a matter of fact, looking down on top of the table (figure 12) one sees four sets of absorbers. At the bottom of figure 12 is shown the set connected with blower F_1 and at the top the set connected with blower F_2. As each sampling can and blower is provided with a double set of soda-lime and Williams bottles, we have two series for blower F_1 withdrawing air from can C_1 and two series connected with blower F_2 withdrawing air from can C_2. With this arrangement we can, by means of valves V_1 and V_2 (fig. 12) and their corresponding valves

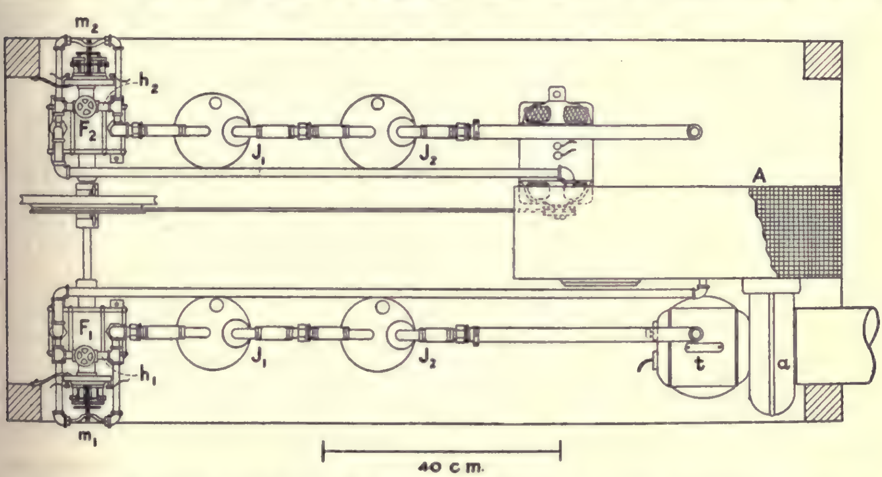

Fig. 11.—Top view of lower shelf of absorption apparatus of group respiration chamber.

The parts are lettered the same as in fig. 8. h_1 and h_2, globe valves for by-passing air-currents from blowers, F_1 and F_2. m_1 and m_2, rubber tubes for fine regulation of amounts of air delivered by blowers. These tubes are opened and closed by telegraph sounders actuated by contacts d_1 and d_2 in fig. 13.

V_3 and V_4, deflect both air-currents from one series of purifiers to the other at the end of any 20 or 30-minute period and thus begin another experimental period without intermission.

This method of treatment assumes at the start that the same amount of air will be discharged through both 10-mm. openings in the bottoms of cans C_1 and C_2. Since the discharge from the rotary air-impeller, a, is somewhat nearer to the opening of the bottom of the can C_1 than it is to the opening in C_2, one might think that there would possibly be more or less of a short-circuiting effect between the discharge of a and the opening B, and inequality in discharge to C_1 and C_2. This difficulty is avoided by a series of wire screens (W, fig. 9) which breaks up practically all air-currents. Tests have shown that the discharge through the two 10-mm. openings is exactly the same.

To measure the amount of air delivered through these openings is a difficult problem. No anemometer thus far devised can record the discharge of air through these holes with a sufficient degree of accuracy for comparison purposes, but the air discharged must be measured for checking; this problem is intimately connected with the problem of collecting and analyzing a sample of the discharged air, for our fundamental assumption is that the large proportion of the air will be discharged into the room free, but a small sample must be collected for analysis. To assume that there will be constancy in the discharge of

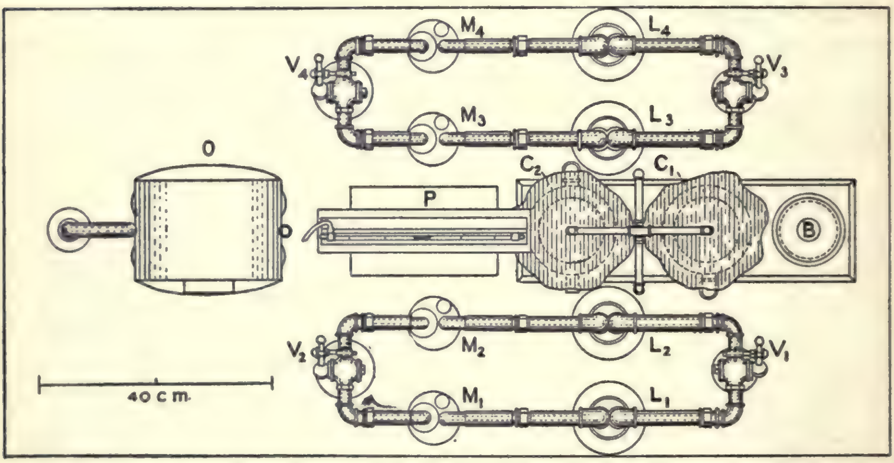

FIG. 12.—View from above of top of absorption table of group respiration chamber.

B, circular opening for delivery of air to outside; C_1 and C_2, cylindrical cans on top of wind chest; L_1, M_1 and L_2, M_2, duplicate sets of soda-lime and sulphuric-acid containers for absorbing carbon dioxide of air coming from C_1; L_3, M_3 and L_4, M_4, duplicate sets of soda-lime and sulphuric-acid containers for absorbing carbon dioxide of air coming from C_2; V_1 and V_2, 3-way valves to deflect air from L_1, M_1 to L_2, M_2; V_3 and V_4, 3-way valves to deflect air from L_3, M_3 to L_4, M_4; *P*, petroleum manometer for indicating pressure in either C_1 or C_2; *O*, meter for measuring amount of air passed through the system.

the air through these various holes presumes that the resistance against which the air is discharged should be the same in all cases, that is, there must be atmospheric pressure outside the openings. To discharge a definite volume of air against atmospheric pressure and simultaneously collect it presents a new problem.

COLLECTION OF AIR SAMPLE.

The collection of the sample of air from the aliquoting device delivered against atmospheric pressure is not unlike an earlier experience in the development of the respiration calorimeter at Wesleyan University. In this apparatus the Blakeslee pump was made to deliver the air of 49 strokes into the room and of the fiftieth stroke into a pan covered with a rubber diaphragm and delicately counterpoised. From

this covered pan air was continuously withdrawn through a series of U-tubes at such a rate that by the time the next sample was ready to be delivered into the pan the first sample had been practically all withdrawn.[1] By this method, however, air was but intermittently dis-

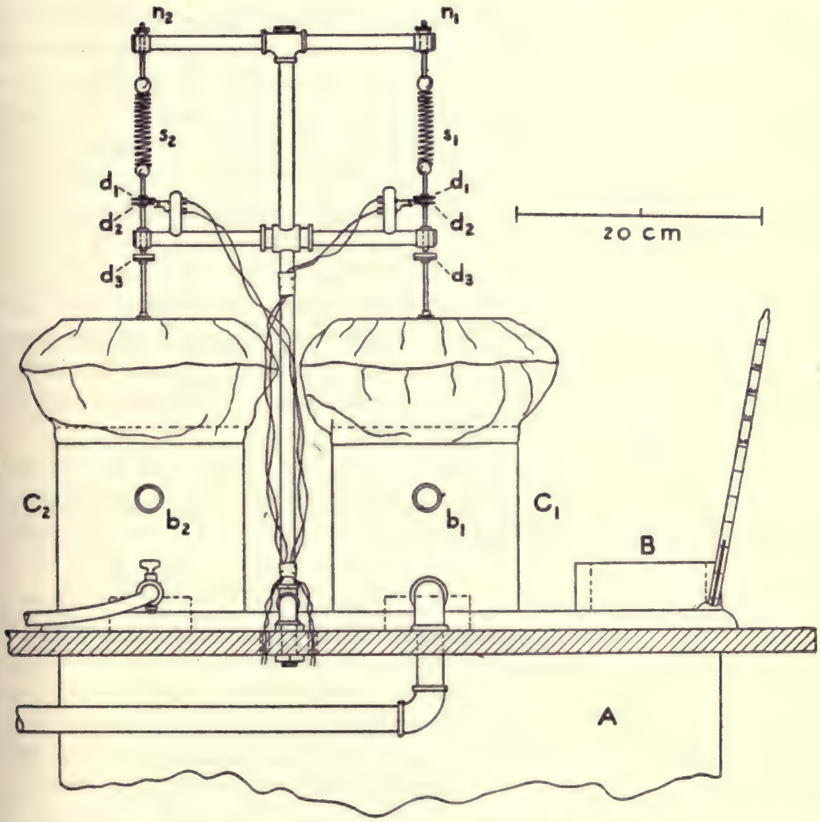

FIG. 13.—Details of device for regulating pressure inside of cylindrical cans above wind chest.

A, wind chest; *B*, opening for delivery of major portion of air to outside; C_1, C_2, cylindrical cans above wind chest; b_1, b_2, openings for delivery of air from C_1, C_2 to outside; the weights of the bathing caps on tops of cans C_1, C_2 are counterpoised by the springs, s_1, s_2, the tensions of which are regulated by the nuts, n_1, n_2; when the pressure inside of cans C_1, C_2 gets too low, the contact shown between disks d_1, d_2 is closed, and the current passing through this circuit draws down the telegraph sounder shown in fig. 11; this permits the opening of tube m_1 or m_2 (fig. 11) and by-passes a portion of the air, thus drawing less air from the can C_1 or C_2. In this way the amount of air drawn from C_1 or C_2 is regulated so that the air inside of either can is practically always at atmospheric pressure. d_3 is a disk for preventing the bathing cap from rising unduly.

charged into the pan and with a pump that, while not capable of exerting any great positive pressure, nevertheless could easily overcome the slight friction of the counterpoise weight of the rubber diaphragm. Our present problem, however, was to remove the air from the samp-

[1] Atwater and Benedict, U. S. Dept. Agr., Office Expt. Sta. Bul. 109, 1902, p. 27.

ling can as rapidly as it was introduced, the air as supplied from the wind chest being under only slight positive pressure, amounting to but a few millimeters of water. It thus became necessary to adjust the receiving chamber so that the pressure of air inside was always atmospheric.

To do this the receiving chambers or sampling cans into which the small orifices opened were made as follows: A copper can was used, which was provided with a cover consisting of a lady's bathing cap, made of pure gum, securely fastened around the edges. The greater part of the weight of this rubber top was borne by a light aluminum disk placed inside the cap. To the disk was fastened an upright brass rod with tight closure about the rod. At the top of this brass rod a hook was attached to a slight spiral spring suspended from a standard. The combined weight of the rod, disk, and rubber cap was thus borne by the spring. Without this suspension effect the weight of the rubber would increase the pressure. With the suspension effect the bag was held in position so that at any one moment there would be complete atmospheric pressure if provision were made to remove the air as soon as it was delivered into the can.

The details of these diaphragms and their suspension and electrical connections are given in figure 13, which shows their normal position when the ventilating air-circuit is not in action, *i. e.*, when counterpoised by means of the delicate spiral springs, s_1 and s_2, at the top. The tension on the springs can be easily adjusted by the nuts n_1 and n_2 and thread on the ends of the suspension hooks. The air coming from the wind chest is thus discharged into a chamber, which, though provided with a flexible top, is nevertheless absolutely air-tight. Since it is necessary in many preliminary adjustments of the apparatus to have a free opening from each of the cans into the air, aside from that leading to the blower, a small piece of brass tubing is soldered into the side of each can at b_1 and b_2. When the apparatus is running, the two pipes are easily closed by inserting solid rubber stoppers.

If the air is removed from this chamber more rapidly than it is delivered, there will be diminished pressure inside the rubber diaphragm, thus pulling down on the spring from which it is suspended. The ultimate result will be a slightly decreased pressure above the opening leading into the wind chest. If, on the contrary, the air is withdrawn more slowly than it is delivered, the rubber diaphragm over the can will distend, raise the aluminum disk, lessen the work of the spring, and produce a slight positive pressure at the orifice into the wind chest. Thus, while air will be delivered free into the room from the large opening, it will be compressed in the rubber diaphragm over the sampling can. It is therefore necessary to remove the air from the sampling can at the same rate that it is delivered in order that atmospheric pressure may be maintained.

REMOVAL OF AIR FROM SAMPLING CANS.

The mechanism for removal of air from the sampling cans must provide not only for absolute uniformity and regulation of removal, *i. e.*, the removal of a volume of air equivalent to the amount discharged into the sampling cans through the 10-mm. openings, but it must likewise force the air thus removed through proper purifiers for the quantitative absorption of water vapor and carbon dioxide, respectively. This may be accomplished by means of either a reciprocating pump or, as with the universal respiration apparatus, by a rotary positive blower. This blower, shown as F_1 in figure 8, is belted with the motor, G, each sampling can having its corresponding blower. (See also fig. 11.) The blowers are actuated by the same electric motor, from the same shaft and hence at the same speed, for since the openings into the bottoms of the cans, C_1 and C_2, are exactly the same diameter and a like amount of air is discharged through both, the volume of air to be taken care of is exactly the same with both blowers. While other and less costly types of blowers have suggested themselves to us and have been subjected to preliminary tests, as yet nothing has been found that compares with the regularity of performance of the somewhat expensive Crowell blower.

The blower is adjusted to remove somewhat more than 45 liters of air per minute, the rate being determined entirely by the size of the pulleys and the speed of the motor. As at present employed, the diameter of the pulley on the blower is 20 cm. Any considerable excess in the amount of air removed in this manner may be controlled by the wheel by-pass shown as h_1 and h_2 in figure 11. This by-pass consists of a connection between inlet and outlet side of the blower, made up of standard brass pipe and fittings provided with a wheel valve. By opening the valve the effectiveness of the blower can be altered at will. Indeed, if it is opened wide no air will pass through the purifying train, since it simply will run back through the by-pass. Thus the amount of air withdrawn by the blowers from the sampling cans may be grossly regulated.

From the construction of the sampling cans and their rubber diaphragms (see fig. 13) it can be seen that, if the air is withdrawn too slowly, the rubber tops will gradually rise and become distended. Conversely, if the air is withdrawn too quickly, they will become more or less collapsed. From the fact that the actual weight of the diaphragm is in large part counterpoised by a spiral spring, considerable fluctuations in the general shape and size of the rubber top of the can may actually take place without a material alteration in the internal pressure on the diaphragm. A slight rise and fall, such as 1 or 2 mm., when so delicately counterpoised, is absolutely without influence upon the tension inside the diaphragm. This fact has been taken advantage of

to actuate a second by-pass on the blower, which is controlled by an electrical magnet.

This by-pass is constructed in the following manner: The pipes on each side of the by-pass, h_1 and h_2 (fig. 11), are extended and reduced in size to permit the insertion of a short length of thin-walled soft rubber tubing, m_1 and m_2. By placing this tubing back of the armature of a small magnet (an inexpensive telegraph sounder has been found suitable for the purpose), air may be allowed to pass at will through the rubber tube by opening or closing the magnet. A vertical movement of the rubber diaphragm of 1 mm. opens or closes a simple electrical contact which is actuated by two small disks (d_1 and d_2, figure 13) on the suspension rod of the diaphragm on each sampling can. This in turn opens or closes the magnet release and hence leaves the passage free or obstructed through the rubber tube of the by-pass m_1 or m_2. The details are shown in figures 11 and 13.

With this arrangement, if the blower draws somewhat too much air out of the sampling can, *i. e.*, more than is delivered to it, the diaphragm tends to fall; this closes the electric contact which, in turn, draws down the telegraph sounder. The normal spring tension against the rubber tube m_1 or m_2 is released by this movement, thus allowing air free passage through the tube. Under these conditions the blower draws too little air from the can and the discharge from the wind chest is somewhat greater than its removal from the sampling can. This results in a slight raising of the rubber diaphragm, the breaking of the electric contact, and the closing of the by-pass m_1 and m_2. This alternate opening and closing is practically continuous, occurring several times each second. Under these conditions the position of the rubber diaphragm remains nearly constant and the pressure of the air inside the sampling chamber is atmospheric.

This constancy in atmospheric pressure may be tested by an extremely delicate Sondén petroleum manometer P (fig. 8), which is so mounted that, by turning a 3-way stopcock, it can be connected with either of the sampling cans at will. If the pressure inside the sampling can is atmospheric, the petroleum manometer indicates 0. The adjustment at the start is easily made by increasing or decreasing the tension on the spiral springs above the rubber diaphragm by means of the small regulating nuts, n_1 and n_2.

If the manometer shows that the pressure is too great inside the can, the weight of the diaphragm has not been suitably counterpoised; hence it is necessary to turn the nut so as to produce greater tension on the spring. When the pressure inside is below atmospheric, the operation is reversed. The small disks which actuate the electric magnet are attached to the vertical rod by tiny set screws and can be adjusted for any elevation. When once adjusted, however, very considerable

alterations in the tension of the spiral spring may be made without the necessity of altering the position of the contacts materially.

Occasionally, through error or otherwise, the blower delivering air to the wind chest is connected before the rubber stoppers[1] in b_1 and b_2 are removed. There is then a great distention of the diaphragm with a tendency to lift the rods so that the contact slips out from between the two small disks (d_1 and d_2, fig. 13). To prevent this a third disk, d_3, is attached to the rod below the cross arm support in such a manner that the rubber diaphragm can not be raised sufficiently to do any harm to the contacts. It has been found advantageous to insulate all the parts by means of fiber washers. Hard-rubber bushings are placed in the top cross-arm, which insulate the entire electrical system from the table.

It is thus seen that we have provided a means for removing air from the sampling cans as fast as it is delivered, to maintain absolute and uniform atmospheric pressure inside them, to insure uniform discharge of air from the wind chest through the two 10-mm. openings and, furthermore, to drive the respective volumes of air withdrawn from the sampling cans through suitable purifying vessels to remove the water vapor and carbon dioxide. The absorption of the carbon dioxide and the weighing of the purifying vessels still remain to be described.

QUANTITATIVE ABSORPTION OF CARBON DIOXIDE.

The complete removal of the carbon dioxide from the air sample and the provision for its quantitative measurement are accomplished by the standard soda-lime bottles and Williams bottles employed in this laboratory for all universal respiration apparatus. If the soda-lime bottle, L, and its accompanying Williams bottle, M (see fig. 8), are weighed prior to the period and again subsequent thereto, the increase in weight of the two indicates the carbon dioxide absorbed during the time, for the air entering L is dried over sulphuric acid in J_1 and J_2 and the air leaving M is dried to the same degree of humidity. The duplicate set of bottles shown in figure 12, controlled by the valves V_3 and V_4, gives an admirable check upon this measurement of carbon dioxide. It is of interest that almost invariably the agreement between the two sets is absolute. Occasionally, when there is faulty adjustment of the pressures inside the sampling cans, there is a slight discrepancy, owing to the fact that if the pressure is greater inside of one can than the other, less air is delivered and less carbon dioxide removed.

The determination of the amount of carbon dioxide in the aliquot is thus simple, namely, the weighing of the two absorbing vessels. The carbon dioxide collected in these vessels does not, however, represent

[1] The stoppers are always in place when an experiment is in progress.

an aliquot of that produced inside the chamber. If there were no subject inside the chamber and if outdoor air alone were drawn through this system, there would still be carbon dioxide absorbed in the weighing bottles, for there is a constant amount of carbon dioxide in outdoor air. Some attempts were made to remove this carbon dioxide entering the chamber by blowing the air delivered by the intake blower (see *k*, fig. 6) through a large scrubber filled with lime. This was found to be impracticable, for the absorbing agents best adapted for the removal of carbon dioxide likewise absorbed considerable amounts of water vapor, became pasty, and obstructed the passage of air. Since the carbon dioxide in outdoor air is such a constant quantity, it was believed that use could be made of this constant and a simple correction applied to the carbon dioxide weighed in the bottles *L* and *M*.

While it was stated that the discharge into the sampling cans is approximately 45 to 50 liters per minute, this is not known exactly. Furthermore, the discharge will vary somewhat with the size of aperture used in the opening *B* (figs. 8 and 9). We can, however, meter the air after it has been discharged from either sampling can, passed through the purifying vessels, and is ready to be discharged into the room. This may be done by passing it through the dry gas meter *O* (see fig. 8), a so-called "3-light gas meter," which has been found satisfactory for the purpose. The meter reads in cubic feet, but metric scales may be obtained, if desired. With the present arrangement of the apparatus, approximately 45 cubic feet of air per half hour are withdrawn from each sampling can. The addition of the meter to the system affects in nowise the discharge into the sampling chamber, meaning simply a slightly greater load for the positive blower, which is already required to force air through two large sulphuric-acid bottles, a system of pipes and valves, a soda-lime bottle, small sulphuric acid bottle, and sodiumbicarbonate can and, finally, through the meter.

By reading the meter at the beginning and end of the period, a fairly accurate measure is obtained of the total amount of air in each sample. If uncontaminated outdoor air is passed through the entire apparatus for several hours, a measurement may be obtained of the amount of carbon dioxide per 100 cubic feet of air or per cubic meter. This test has been made repeatedly. While slight fluctuations are found, the values are, on the average, very close to 1.48 grams of carbon dioxide per 100 cubic feet with the particular meter used. The correction for the carbon dioxide in the ingoing air is thus made by simply multiplying the reading obtained from the gas meter in cubic feet by the factor 1.48 grams per 100 cubic feet, and deducting the result from the weight of carbon dioxide absorbed. The remainder corresponds to the carbon dioxide in the sample which was produced by the subject inside the chamber.

TEST OF ALIQUOTING DEVICE.

While the calculation of the several areas of the three discharge openings from the wind chest gives an approximate estimate of the relative amount of air that will be discharged, on the fundamental assumption that the air thus expelled will be directly proportional to the area of a cross-section of the orifice, nevertheless in any accurate use of the apparatus, such a gross assumption can not go unchallenged. It accordingly became necessary from the earliest development of this apparatus to check quantitatively the relationship between the two 10-mm. openings and the large opening with its various reductions. For this purpose a small auxiliary chamber (approximately 1 cubic meter in size) was connected with the pipe leading to the air-impeller (*a*, fig. 8) on the sampling apparatus. Into this chamber a known amount of carbon dioxide was admitted from a steel cylinder of liquefied carbon dioxide. These cylinders held approximately 2.5 kilograms each. The gas was found to be of an extraordinarily high degree of purity, with practically no appreciable correction for the slight amount of dissolved air. By weighing this cylinder of carbon dioxide on a balance capable of recording 1 centigram, 100 to 400 grams could be admitted as rapidly or as slowly as desired. Repeated tests with the subsidiary chamber showed that the aliquoting device functioned perfectly, regardless of whether the carbon dioxide was rushing into the chamber as rapidly as possible or entering very slowly over a long period.

By knowing (1) the amount of carbon dioxide admitted to the chamber as shown by the difference in weight of the cylinder at the beginning and end of the test, (2) the amount of carbon dioxide absorbed in the soda-lime bottle, and (3) the volume of air passing through the gas meter, the ratio could be computed between the 10-mm. openings and the particular opening used for the large discharge from the wind chest. For experimental purposes several disks with orifices of varying size were prepared. These disks were made of brass, were 1.5 mm. thick, and 110 mm. in diameter. They had a rim of sheet brass 40 mm. wide, soldered into the edge, thus forming a cup which could be dropped into the annular space filled with water surrounding the large opening of the wind chest. Disks were made with orifices of approximately 60, 40, 29, 22, and 16 mm., respectively. The true diameters of these disks, as found from a series of exact caliperings, are as follows: 16-mm. disk, diameter 15.92 mm.; 22-mm. disk, diameter 22.03 mm.; 29-mm. disk, diameter 28.75 mm.; 40-mm. disk, diameter 40.00 mm.; 60-mm. disk, diameter 59.52 mm. A careful calipering of the main discharge opening showed an average internal diameter of 97.00 mm. The true diameter of the 10-mm. openings was 10.11 mm. In all subsequent references to these various openings, they are given the number

representing the nearest millimeter. It so happens that in the work with the diet squads we had occasion to use only the 60 and 40 mm. disks.

The tests with the subsidiary chamber showed that a definite proportion of the carbon dioxide admitted was invariably recovered in the soda-lime bottle, this amount being constant for the individual disk used in the main discharge opening, but varying with the size of the disk. Furthermore, it was found that the amount of carbon dioxide collected in both sets of absorbers was invariably the same, proving that the discharge of air through the two 10-mm. openings was identical.

With the subsidiary chamber various other tests were made to study the influence of both slightly decreased and slightly increased pressure on the intake side of the main blower. Furthermore, since variations in line voltage are to be expected with consequent change in shaft speed, it was important to note whether such changes affected the aliquot or not. Changes in line voltage and shaft speed of the blower were therefore studied, but the aliquoting device of the wind chest with its three openings showed invariably the same proportion of air discharged through the individual openings.

All of the preliminary tests were carried out with the subsidiary chamber. After the tests were completed and the sampling apparatus attached to the group respiration chamber, quantitative tests were made by introducing liquefied carbon dioxide into the larger chamber. With the subsidiary chamber the residual air could be considered as atmospheric, inasmuch as but a few seconds were required to ventilate the chamber completely and sweep out any carbon dioxide admitted. But in the tests with the group chamber it was necessary to make residual analyses of the air inside the chamber at the beginning and end of each test, as with the disks 60 mm. or less in diameter, a long time would be required to sweep out completely the carbon dioxide admitted and reduce the percentage of carbon dioxide in the air to that of outside air.

These tests have been repeated many times throughout the two years that the apparatus was in the process of development and a standard factor found for each size of disk to indicate the percentage of the total carbon dioxide withdrawn from the chamber which was collected in the soda-lime bottles, due correction being made for the carbon dioxide in the ingoing air. The ratio for the individual disks was invariably constant, irrespective of the chamber used, barometric pressure, speed of admitting carbon dioxide, and shaft speed of the rotary blower and consequent pressure inside the wind chest; at least, the ratios were constant within the ranges of pressure change possible with the rotary air-impeller, for we deal here with actual pressures corresponding to no more than those equivalent to a few millimeters in water pressure.

The ratios found for the several disks are as follows: 16-mm. disk, 21.21 per cent of air passing through absorbers; 22-mm. disk, 14.37 per cent; 29-mm. disk, 10.00 per cent; 40-mm. disk, 5.60 per cent; 60-mm. disk, 2.54 per cent. The ratio for the main discharge opening (97 mm.) was 1.14 per cent.

The carbon-dioxide tests with the subsidiary chamber were primarily made to establish the several factors. They were then in a sense reversed in that the factors thus established were employed in determining the known amounts of carbon dioxide admitted into the large respiration chamber; the agreement of these checks is all that could be desired.

RESIDUAL ANALYSIS.

In observations on domestic animals, or with a group of men, extending over a considerable period of time, small changes in the actual amount of carbon-dioxide residual in the chamber at any given time are practically without influence upon the final results. When, however, the experimental period is shortened to such an extent that variations in the residual amount inside the chamber may become a measurable proportion of the total amount withdrawn during the period, the necessity of a careful determination of the residual amounts is obvious. This feature of the apparatus, which plays no rôle in experimenting with domesticated animals when long experimental periods are employed, requires the use of a gas-analysis apparatus for short experimental periods with humans. Practically all of our work was carried out by using a Sondén-Pettersson gas-analysis apparatus,[1] which made it possible to determine the carbon dioxide to approximately 0.001 per cent. Since the total volume of the chamber was not far from 44,000 liters, it will be seen that each one thousandth of 1 per cent carbon dioxide corresponded, roughly speaking, to 0.9 gram of carbon dioxide; hence the accuracy was all that could be desired.

In the latter part of our experimenting during the season of 1917–18 we were much attracted by the accuracy of the small Haldane apparatus for carbon dioxide alone.[2] This gives an accuracy for carbon-dioxide measurements that for the great majority of experiments is perfectly satisfactory. The apparatus is simple, relatively easy to manipulate, very rapid, sufficiently compact to be portable and has none of the fragile parts so essential to the Sondén apparatus. Our experience with the various types of Pettersson apparatus which have been put upon the market has been upon the whole rather unsatisfactory.

While in the large majority of our observations on Squad A, corrections for the residual air were not only unnecessary but at times, owing to errors of gas analysis, positively disadvantageous, we have in practi-

[1] Benedict, Carnegie Inst. Wash. Pub. No. 166, 1912.
[2] Haldane, Methods of air analysis, 1912, p. 62.

cally all instances corrected our periods for changes in the residual analysis, the analyses being for the most part made with the Sondén apparatus. Similarly, in check tests, in which the carbon dioxide was admitted to the large chamber from a steel cylinder and the carbon dioxide was determined in short periods, the residual analysis played a very important rôle, for the introduction of the carbon dioxide into the chamber was extremely irregular. On the other hand, with a group of normal men or women pursuing a certain definite procedure such as reading or walking, the carbon-dioxide production becomes very regular after a very short time. In certain instances the accuracy of the Sondén apparatus for finding the residual carbon dioxide was determined by having no ventilation in the chamber, analyzing the air at the start, introducing a certain amount of carbon dioxide, analyzing the air at the end, and comparing the carbon-dioxide content of the air at the beginning and the end of the test. This type of check also gave most gratifying results whenever used.

The humidity and temperature of the air inside the chamber were determined by the wet and dry bulb thermometer, easily read through the glass window. The method of calculation is indicated in detail for a single experimental period in table 4, and the summary of results of an entire night experiment in table 5.

TABLE 4.—*Typical calculation of a period with the group respiration chamber (12^h32^m—1^h02^m a. m. Oct. 7, 1917.)*

*Calculation of residual carbon dioxide in the chamber.**

Observations.	At 12^h32^m a. m.	At 1^h02^m a. m.
Barometer	768.60 mm.	768.75 mm.
Temp. barometer	20.0°C.	20.0°C.
Temp. dry bulb	18.7°C.	18.9°C.
Temp. wet bulb	15.3°C.	15.4°C.
Per cent CO_2	0.191	0.195
	Logarithms.	Logarithms.
$(p-e)/760$	9.99725–10	9.99733–10
$1/1+0.00367t$	9.97117–10	9.97088–10
Volume of chamber	4.63925	4.63925
Per cent CO_2	7.28103–10	7.29003–10
Liters to grams	0.29320	0.29320
Total residual CO_2	2.18190 = 152.0 grams.	2.19069 = 155.1 grams.
Change in residual CO_2 = +3.1 grams.		

Calculation of carbon dioxide produced during the period.

Carbon dioxide absorbed from aliquot of outgoing air	Set No. 1 = 4.43 grams. Set No. 2 = 4.43 grams.
Volume of aliquot of outgoing air	= 47.79 cu. ft.
CO_2 of aliquot from ingoing air	$= 0.4779 \times 1.48 = 0.71$ gram.
CO_2 of aliquot produced in chamber	$= 4.43 - 0.71 = 3.72$ grams.
CO_2 produced in total outgoing air	$= \frac{3.72}{2.54^{**}} \times 100 = 146.5$ grams.
CO_2 produced by squad	$= 146.5 + 3.1 = 149.6$ grams.

* After Nov. 11, 1917, it was assumed that each 0.001 per cent change in the residual corresponded to 0.8 gram of CO_2 and calculations were no longer made.

** 2.54 equals the percentage of the total outgoing air that actually passed through one set of the absorption system, *i. e.*, the factor for the 60 mm. disk.

TABLE 5.—*Summary of carbon-dioxide measurements with the group respiration chamber on night of Oct. 6–7, 1917.—Squad B.*

Time of end of period.	Residual carbon dioxide in chamber by analysis.	(a) Change in residual content of carbon dioxide.	Analysis of aliquot.				(f) Carbon dioxide produced by squad. $\left(e \times \frac{100}{2.54^1}\right) \pm a$	(g) Carbon dioxide produced by squad per hour.
			(b) Carbon dioxide from ingoing air.	Carbon dioxide absorbed from outgoing air. (c) Set No. 1	Carbon dioxide absorbed from outgoing air. (d) Set No. 2	(e) Carbon dioxide corrected for amount from ingoing air. $\left(\frac{c+d}{2} - b\right)$		
	per cent.	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*
12^h02^ma.m..	0.193	....	....	....	....	....	....	....
12 32 a.m..	.191	−1.7	0.70	4.37	4.38	3.68	143.2	286.4
1 02 a.m..	.195	+3.1	.71	4.43	4.43	3.72	149.6	299.2
1 32 a.m..	.193	−1.8	.71	4.51	4.48	3.79	147.4	294.8[2]
2 02 a.m..	.192	−0.9	.71	4.49	4.40	3.74	146.3	292.6[2]
3 02 a.m..	.191	−0.9	1.42	8.80	8.79	7.38	289.7	289.7[2]
4 06 a.m..	.199	+6.5	1.51	9.39	9.35	7.86	316.0	296.3
5 06 a.m..	.197	−1.4	1.41	9.04	9.00	7.61	298.2	298.2
6 06 a.m..	.201	+3.2	1.42	9.31	9.19	7.83	311.5	311.5

[1] 2.54 equals percentage of total outgoing air actually passing through one set of the absorption system.

[2] Periods from $1^h.02^m$ to $3^h.02^m$ a. m. selected as minimum periods. The average of these is 292 gms. CO_2 per hour. Total body-surface of squad equals 21.8 square meters. Assuming 3.025 calories as heat equivalent per gram of CO_2 at a respiratory quotient 0.81, the heat per square meter would be found by the following calculation:

$$292 \times 3.025 \div 21.8 = 40.5 \text{ calories per square meter per hour.}$$

ARRANGEMENTS FOR SLEEPING.

Night experiments alone were made in our use of this apparatus in the diet research. Twelve beds were provided in 3 sections of 4 beds each, as shown in figure 5, page 92. Good springs with suitable bedding made comfortable sleeping quarters. Glass jars for night urine were hung in wire frames at the foot of each bed.

TECHNIQUE FOR DETERMINING EFFECT OF MUSCULAR WORK.

The men in Squads A and B were all engaged in various forms of muscular activity, ranging from the severe exercise of leading gymnasium classes for several hours a day to that of the activity necessary for moving about the campus from building to building. Even our most inactive man showed a considerable amount of muscular activity according to his pedometer and physical activity records. It was important, therefore, to determine the effect of the reduced diet on muscular activity and the physiological phenomena accompanying it.

MEASUREMENT OF WORK OF BICYCLE RIDING.

For this purpose we fortunately obtained the cooperation of Professor A. G. Johnson, of the faculty of the International Young Men's Christian Association College. As a part of an extended study upon the influence of muscular activity upon the heart rate, which had been

carried out for a number of years at the college under the direction of Professor J. H. McCurdy and Professor Elmer Berry, a study was made of the length of time required for the heart rate to return to normal after a definite amount of muscular work. Use was made of a bicycle ergometer belonging to the Nutrition Laboratory, which has been described in detail in an earlier publication.[1] This was shipped to Springfield, there connected with a storage battery consisting of fifteen 1.5 volt Edison cells, and a mil-ammeter and sliding resistance placed in circuit. By controlling the current passing through the fields of the ergometer, holding it constant at 1.35 amperes, and adjusting the rate of revolution of the pedals by means of a metronome beating 80 per minute, the subjects performed a definite amount of work for a period of 5 minutes. After mounting the ergometer, the man rode for an exact period of 5 minutes at the rate of 80 pedal revolutions per minute. Upon the completion of the 5-minute period, he lay down upon a bench and the pulse-rate was counted for the first 15 seconds of every minute until the normal resting pulse for the day was reached.

MEASUREMENT OF GASEOUS METABOLISM DURING WORK.

Measurements of the gaseous metabolism of man while engaged in muscular work have been made by different investigators and include such varied forms of work as riding a bicycle ergometer, lifting weights, turning a wheel, and walking on a horizontal or inclined path both out-of-doors and on a treadmill in a laboratory. In selecting the form of muscular exercise for experiments on muscular work, walking seemed most suitable on account of its being the natural and universal form of exercise. It brings into play a large number of muscles of the body and at the same time the element of training is practically negligible. Furthermore, the Nutrition Laboratory was equipped with apparatus for experiments in this line and considerable published and unpublished data were available upon which to draw for necessary comparison. Accordingly, in addition to the work done with the ergometer, a considerable number of observations were carried out with a treadmill. The first set of experiments was made with Squad B on January 6 before their diet restriction began. This was followed with the same squad on January 28 after a 20-day restriction of diet and on February 3 experiments were made with Squad A after four months of diet restriction. In these experiments the subject walked a definite distance at a definite speed and determinations were made of the carbon dioxide excreted, and the oxygen consumed.

Since the use of any form of mouth or nose appliance in metabolism measurements is open to criticism and requires some practice to avoid respiratory disturbances it was decided to build a closed chamber large

[1] Benedict and Cady, Carnegie Inst. Wash. Pub. No. 167, 1912, p. 5; see description of Ergometer No. II.

enough to contain a treadmill and a subject walking on it. Thus all objections to the use of the mouthpiece and nosepieces would be avoided and the subjects would have much greater freedom of head and body movements while walking than when joined to a circulating air system by a mouthpiece. In fact, the subjects were as free as when walking in the open room. The temperature within the chamber could be controlled by cooling the air of the room by open windows and electric fans and the humidity kept at a low point by circulating the air of the chamber through a drying system. Under these conditions the gaseous exchange could be computed from the volume of the chamber, the percentage increase of the carbon dioxide, and the decrease in the oxygen in the air of the chamber during the period of walking.

It was also considered possible by this method to make one 20-minute walking period suffice for each subject. By taking the samples of air for analysis in duplicate the possibility of error from this source would be slight. As a further check, however, it was planned to draw air samples for carbon-dioxide determinations at 10-minute intervals, thus dividing the walking period into two 10-minute periods, which should show agreement in the carbon dioxide present.

The walking during the experiments was done on a treadmill which is described briefly on page 126, and more in detail in another publication.[1] This treadmill was placed inside the specially constructed chamber; both treadmill and chamber are shown in figure 14.

THE TREADMILL CHAMBER.

The treadmill chamber was, for convenience in handling, constructed in three parts; the base *A*, the skirt *B*, and the cover *C*. These parts were made of Nos. 24 and 28 galvanized sheet iron.

The sheet iron base, *A*, was formed over a platform 12.5 cm. high, 223 cm. long, and 88 cm. wide, made of spruce strips and matched floor boards to give the necessary support and rigidity for the heavy mill. The edge of the base was shaped into a trough, *a*, 4 cm. wide and 8 cm. deep, which was filled with a light non-viscous oil. The skirt, *B*, fitted into this trough and the oil made an air-tight seal between the base and the skirt.

The skirt, *B*, was of such a shape that it fitted rather snugly over the mill, having a clearance of 6 cm. at the ends and 5 cm. at the sides, and rising towards the center in the general form of a blunt wedge with an opening at a height of 62 cm. above the leather belt. The upper opening of the skirt was approximately 81 cm. square and was shaped with a trough 6 cm. deep and 4 cm. wide, thus forming a second seal (*b*) similar to that of the base; into this the cover (*C*) fitted. The seal *b* was filled with water, for if oil were used the frequent raising and lowering of the cover and consequent drip from the edges would make

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 34.

it difficult to keep the apparatus clean. On the other hand, when the skirt was once put in place in the oil seal *a* of the base, it was not necessary to disturb it except to get at the lower part of the mill for oiling or for attention to the motor.

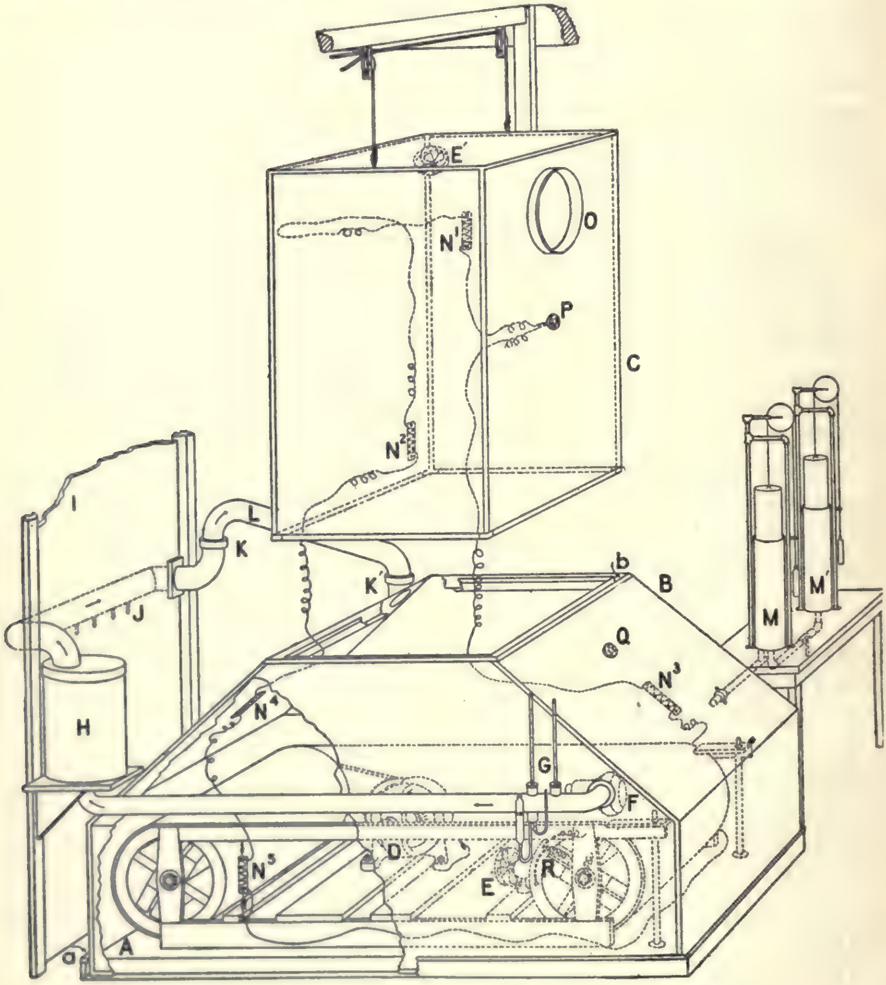

Fig. 14.—The treadmill chamber.

The treadmill rests on the base *A*, which has an oil seal, *a*, into which the skirt *B* fits. The subject stepped over the side of the skirt on to the treadmill and the cover, *C*, was lowered into the water seal, *b*, of the skirt. The treadmill was driven by the motor *D*, controlled by resistances not shown in the figure. Fans *E* and *E′* stirred the air and a blower, *F*, forced the air past the psychrometer, *G*, through the drier *H*. From *H*, the pipe went through a partition, *I*, into an adjoining room where samples of air were drawn at *J* for analysis. The air returned to the chamber through *L*, which was removable at the water seals *K* and *K′*. *M*, the tension equalizer or spirometer connected to a reserve spirometer *M′*. N_1, N_2, N_3, N_4, and N_5, resistance thermometers in series; a sixth one is not shown in the figure. *O*, window; *P*, electrical plug for temperature and pulse leads. *Q*, electrical plug for distance and step counters. *R*, electrical contact for recording revolutions of front pulley.

The cover, *C*, was prism-shaped, 134 cm. high and 79 cm. square on its base, which fitted into the seal of the skirt. It was counterpoised over pulleys on the ceiling and could be easily raised from the seal, giving a clearance above the skirt of 66 cm. A circular plate glass window, *O*, 25 cm. in diameter, was inserted in the front of the cover.

In addition to these main features there were the following accessory parts:

Air-drier (*H*) and psychrometer (*G*); tension equalizers (*M* and *M′*); resistance thermometers (N^1 to N^5); barometer; and gas-analysis apparatus.

AIR-DRIER AND PSYCHROMETER.

From the right side of the skirt near the front a 6 cm. pipe extended along the side of the skirt to a drier (*H*) 40 cm. high and 30 cm. in diameter, filled with 15 kg. of fused calcium chloride. The calcium chloride was in small lumps about 1 cm. in diameter, which allowed a free passage of the circulating air. It was fairly efficient in absorbing power, and kept the humidity within the chamber at a point varying from 20 to 50 per cent. The psychrometer, *G*, was inserted at the point where the 6 cm. pipe left the skirt.

From the drier a 10 cm. pipe, *J*, carried the dry air back to the chamber which it entered at the rear of the skirt. This return pipe had a total length of 250 cm. and the mill was so located in the room that 100 cm. of this pipe passed through and extended horizontally along the face of the doorway, *I*, of an adjoining room. In this part of the circuit were inserted the stopcocks through which air samples could be simultaneously withdrawn. The doorway was closed up so as to provide a room of reasonably constant temperature for the gas analysis. The last section of this return pipe, *L*, was made removable by means of two small water seals, *K* and *K′*, so that, when this section was lifted from its connection with the chamber, the large cover could be lowered into or raised from the skirt without altering the tension of the air inside the chamber.

VENTILATION OF CHAMBER.

A "Sirocco" blower, *F*, within the chamber, attached to the circulating air pipe at the point where it left the skirt, maintained an air-current through the system of 1,000 liters a minute. An electric fan, *E′*, was placed in the top of the cover in such a position as to send a current of air over the head and shoulders of the subject, while a similar fan, *E*, was placed under the belt between the two pulleys of the treadmill. These two fans, *E* and *E′*, together with the circulating air-blower, *F*, previously referred to, were relied upon to keep the air well mixed within the chamber during the active periods of walking. In addition to these a large 15 cm. blower, capable of delivering 12 cubic meters of air a minute, was mounted outside on a table which could be rolled up to the side of the skirt. During the intervals between the

experiments with the series of subjects, this blower was kept in operation to sweep out the air in both skirt and cover. Two windows on opposite sides of the room gave a rapid means of ventilation.

TENSION EQUALIZERS.

On the left side of the skirt near the front was soldered a 2.5 cm. coupling, to which were connected two spirometers, M and M', with a capacity of 7.2 liters each. These spirometers were connected in series by a 3-way valve and were designed to allow for any change in volume of the chamber due to barometric or temperature conditions. Only one spirometer was regularly used, the second being kept in reserve for any sudden and unexpected changes which might occur. In practice it was found that any ordinary changes in volume could be controlled by changing the temperature of the room; at no time was it necessary to use the second spirometer.

The position of the spirometer was read on a millimeter scale at the beginning and end of each period under a uniform pressure as indicated by a Sondén oil manometer attached to the skirt of the chamber. The spirometer had been previously calibrated and each change of 1 mm. in the level of the spirometer bell was equivalent to a change in volume of 21.5 c.c.

RESISTANCE THERMOMETERS.

The temperature of the chamber was measured by means of six resistance thermometers, made of silk-covered No. 33 copper wire which was wound on wooden frames 4 by 15 cm. These were fastened to the walls of the chamber by studs 35 mm. long. One thermometer, N^1, was placed near the top, another, N^2, near the bottom of the cover, one each (N^3 and N^4) was placed at the front and back of the skirt, respectively, about 20 cm. above the belt of the treadmill, while the remaining two (only one, N^5, is shown in the figure) were placed below the belt near the rear and front pulleys of the mill. The six thermometers were connected in series and had a total resistance of 98 ohms. The leads left the chamber by means of brass rods, which passed through a hard-rubber plug, P, set into the front of the cover by means of gaskets and bushings. From this plug double leads of No. 14 copper wire carried the current to a galvanometer and Wheatstone bridge in the adjoining gas-analysis room. Readings of 0.003 ohm were made, corresponding to a temperature difference of 0.01° C.

BAROMETER.

The barometer was a standard observatory pattern graduated so that 0.05 mm. could be read by means of the vernier.

GAS-ANALYSIS APPARATUS.

The carbon dioxide in the chamber was determined in duplicate by means of two small Haldane gas-analysis apparatus.[1] These instru-

[1] Haldane, Methods of air analysis, 1912, p. 62.

ments permitted determinations of carbon dioxide up to a concentration of 1 per cent. This figure controlled to some extent the size of the chamber and the amount of work to be performed, for too large a chamber would give too great a dilution, while too heavy work would exceed the capacity of the apparatus for the carbon-dioxide determinations. Both instruments had been calibrated against the Sondén gas-analysis apparatus described in an earlier publication[1] and the results used in the calculations are with few exceptions the average of the duplicate determinations.

While the carbon-dioxide determinations could easily be made within the 10-minute divisions of the walking period, the oxygen determination, which involved the use of the Sondén apparatus, required 30 minutes and was obtained only at the end of the walking period. The method by which the oxygen present at the beginning of the period was calculated is explained on page 134.

VOLUME OF CHAMBER.

The total volume of the chamber was determined by allowing a known weight of carbon dioxide to escape slowly from a weighed cylinder into the bottom of the chamber and discarding the displaced volume of air that was thereby forced into the spirometer.

Samples of air were withdrawn for analysis both before and after the addition of the carbon dioxide. A thorough stirring of the air preceded the withdrawal of the samples in each case and the temperature and barometer readings were likewise made at the time the samples were withdrawn. From the known volume of the carbon dioxide added and the increase in the percentage of carbon dioxide found, the volume of the chamber was computed. Four determinations gave 2,437, 2,431, 2,435, and 2,374 liters, with an average of 2,419 liters. An example of the method of calculation of the volume follows:

CO_2 added = 24.00 gms. Observed barometer = 761.58 mm. Temp. = 21.32° C.
CO_2 in chamber at start = 0.048 per cent; after addition = 0.588 per cent; increase = 0.540 per cent.
24.00 gms. CO_2 = 12.218 liters at 0° C. and 760 mm. 12.218 liters = 0.540 per cent of chamber.

$$\frac{12.218}{0.540} \times 100 = 2{,}263 \text{ liters.}$$

This is the volume at 0° C., 760 mm., and dry. The apparent volume is the volume at the observed temperature and pressure and this volume includes the water vapor as well as the atmospheric gases. The volume of 2,263 liters must be corrected, therefore, to the observed temperature and pressure readings. As this includes the water vapor, no deduction for aqueous tension is made from the barometer readings. The correction is made as follows:

$$2{,}263 \times \frac{760}{761.58} \times \frac{294.32}{273} = 2{,}435 \text{ liters.}$$

[1] Benedict, Carnegie Inst. Wash. Pub. No. 166, 1912, p. 75.

From a knowledge of the volume of the chamber and the percentage composition of the air at the beginning and end of the experiment, it was possible to calculate the total amount of carbon dioxide produced during the period of walking, and, from the time involved, the production per minute. In the same manner the percentage of oxygen at the beginning and end would give the amount of oxygen consumed on the per minute basis. From the gaseous exchange thus secured, the respiratory quotient was obtained and the heat produced was calculated by indirect calorimetry. The detailed method of the calculations and certain corrections required are given on page 134.

MEASUREMENT OF WORK PERFORMED DURING WALKING.

In the experiments in which the subject walked upon the treadmill, the distance walked and the rate of walking were recorded, also the number of steps taken. The body-weight and other characteristics of the men were likewise taken into account. In this research it was found impracticable to complicate the apparatus by adding the device employed by Dr. Carl Tigerstedt[1] to indicate the up-and-down motion of the body while walking.

It must be remembered that in these experiments the subject was walking in an inclosed chamber and was thus inaccessible to the operators during the experimental period. Although the small circular window gave the man an opportunity to look out, it did not provide sufficient light to allow the operators to make observations of conditions within the chamber, and all recording devices therefore had to be outside the chamber proper. Furthermore, the chamber had to be air-tight, which required extra precaution in its construction and limited in a large measure the manner by which these recording devices could be attached.

The treadmill used was designed by Mr. E. H. Metcalf, formerly of the Nutrition Laboratory staff, and has been described in detail elsewhere.[2] It has proved most satisfactory and can be adjusted to practically any degree of speed. It has been the experience of subjects walking upon this treadmill that it represents very closely free walking upon a smooth sidewalk. To eliminate the element of novelty, the subjects were given 5-minute periods of walking beginning Nov. 10, every time they came to Boston, so that when the final quantitative test was made, the men would be thoroughly familiar with the apparatus and its technique.

The treadmill, with connections and accessories, is shown in figure 14 in its location in the chamber. Briefly, the treadmill consists of a leather belt 58 cm. wide passing around two wooden pulleys 41 cm. in

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[1] Reported by Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 39.
[2] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 34.

diameter. The belt is 435 cm. long and the portion on which the subject walks is supported by steel tube rollers with ball bearings.

The mill was driven by a 220-volt, D. C., $\frac{1}{2}$ H. P. motor (*D*) placed in front of the rear pulley, to which it was connected by a chain drive and reducing gears. The line to the motor entered the chamber between the base and skirt by being bent U-shape to conform to the trough of the base. Two variable resistances were inserted in the line at the observer's table for regulating the speed of the mill.

In order to have the experiments with the different subjects as comparable as possible, it was necessary to have the speed at which the subject was walking under constant observation and control. In previous experimenting a measure of the speed of the treadmill was obtained by means of a mechanical counter which recorded the revolutions of the front pulley of the treadmill. As the treadmill in this research was inclosed in a chamber, it became necessary by an electrical device to transmit these revolutions to a counter which could be under constant observation. This was done by attaching to the periphery of the front pulley a brass segment which made a wipe contact with a laminated brass finger fastened to the frame of the mill. With each revolution of the pulley an electric contact was made which actuated a counter placed on the observer's table and known in the telephone trade as a "p. b. x. message register." (See fig. 15.) As a precaution two such contacts and counters were installed and connected by a double-throw switch. In practice, however, no difficulty was experienced and only one counter was used.

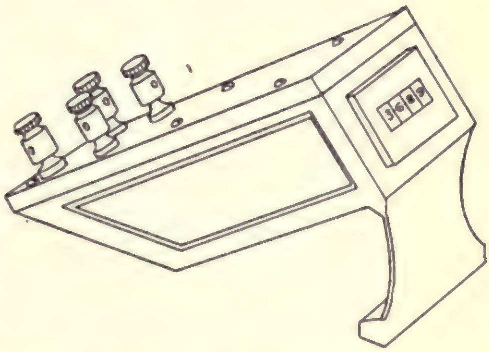


Fig. 15.—Electrical counter.

The message register is shown mounted in a specially designed support which places it conveniently for reading.

To test the speed of the mill the time required for 10 revolutions of the pulley as recorded by the counter was noted with a stop watch, and by reference to a previously prepared chart the speed was immediately known. After the proper rate was established, which rarely occupied over a minute, further observations were taken every 2 minutes, and any adjustment that seemed necessary was easily and quickly made by the adjustable resistance. As a rule very little adjusting had to be done after the first 2 minutes and the speed was very constant. With uniformity of speed there was naturally uniformity in the distance

traveled during the periods, but there was always the possibility that on account of poor contact the counter might fail to register or that an occasional chatter of the contact might cause an extra number to be recorded.

To guard against this possibility, advantage was taken of the construction of the message registers which allowed the connection of a second circuit. This second circuit was carried to a signal magnet and a Blix-Sandström kymograph. With each operation of the message register this separate circuit was also completed through the signal magnet. As the kymograph was uniform in its movement, any skip or extra count in the message register would at once be apparent in the spacing of the signal magnet tracings on the kymograph. The records show no such irregularities and the numbers read off the message registers are believed to be accurate for the revolutions of the pulley. The counter was read at the beginning and end of a period. From these records and from the circumference of the pulley and the length of the experimental period, computations could be made of the total distance traveled and the rate per minute.

Factors which have to be considered when comparing the metabolism of different individuals during horizontal walking include the weight moved and the distance traveled in unit time.

It has been shown[1] that the energy expended during horizontal walking when calculated on a basis of kilogram weight and meter distance increases very slightly with the rate of walking up to a point of approximately 80 to 85 meters per minute. This point has been termed the "speed of maximum efficiency." At this point there appears to be a break in the curve and any increase in speed is done at a relatively greater cost in energy expended. Brezina and Kolmer[2] have shown that within this optimum range of speed the metabolism per kilogram and meter distance is independent of the weight carried up to a load of 20 kg.

It was desirable, then, to maintain a rate of walking within this optimum limit and a rate of 70 meters per minute was selected. This is a fair rate of walking and does not in 20 to 25 minutes introduce the element of fatigue. This rate was also convenient because the amount of carbon dioxide eliminated during the time available for the experiment, judging from other data, would in all probability not exceed 1 per cent of the chamber volume. The capacity of the Haldane gas-analysis apparatus used for the carbon-dioxide determinations was 1 per cent, as previously stated, and it was desired to use this small apparatus rather than other larger and more complicated forms. Furthermore it was desirable not to have so great a concentration of carbon dioxide

[1] Durig, Denkschrift. d. math.-natur. Kl. d. kaiserl. Akad. d. Wissenschaften, 1909, **86**; also Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 85.

[2] Brezina and Kolmer, Biochem. Zeitschr., 1912, **38**, p. 142.

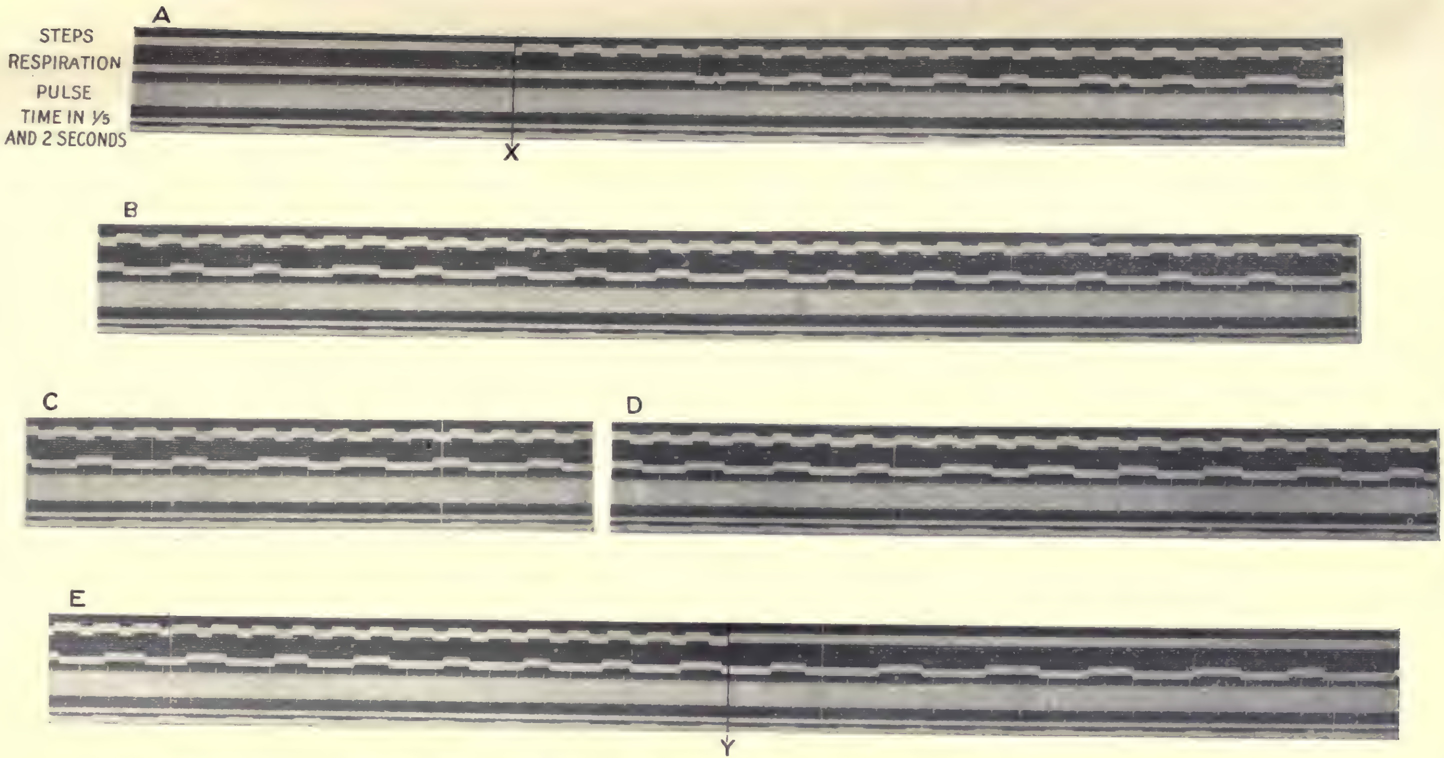


FIG. 16.—Photographic record of the pulse, respiration, and steps of *Bro* while he was walking in the treadmill chamber.

A and *B*, record for the standing-walking period. *A* and *B* together composed one continuous record which has been cut in two approximately equal lengths for illustration. *X*, point at which walking began. *C*, record at end of sixth minute. *D*, record at end of twenty-fourth minute. *E*, record for the walking-standing period. *Y*, point at which walking ceased.

within the chamber that a marked stimulus to the pulse or respiration would be produced.

THE STEP RECORDER.

A record of the steps taken during walking was obtained by a small electrical contact device at the rear of the treadmill to which the subject's left foot was attached by a long coil spring. The spring had sufficient tension to operate the contact when the foot was thrown forward, but at the same time was so weak that it was not noticeable to the subject as he walked. The electric contact operated a message register, also a signal magnet placed before the camera which was used in connection with the string galvanometer for the pulse records. By the latter, photographic records showing the steps were secured on the same paper with the electrocardiograms which were taken at the close of the first, sixth, twelfth, and twenty-fourth minutes of walking. A specimen record is shown in figure 16 with the pulse records.

There was an occasional chatter of the signal magnet due to a rebound by the coil spring. This chatter is in most cases evident in the spacing on the records and such irregular movements of the signal magnet are neglected in the counting. From these records is found the number of steps per minute at the time of the observations and the average of these is used as the steps per minute for the period.

PULSE-RATE.

In order to secure pulse records while the subjects were walking, leads from the string galvanometer in the psychological laboratory were carried to the room where the treadmill was situated and entered the chamber through the hard-rubber plug in the front of the cover (see *P*, fig. 14). The leads terminated inside the chamber in a receptacle into which the subject plugged the terminals of the body electrodes after he entered the chamber. These electrodes were the same as those used in securing electrocardiograms during short periods of muscular exertion. They are shown in figure 26 and described on page 153.

Since there was always a certain amount of electrical leakage from the treadmill motor, as well as static electricity of the leather belt, it was necessary to protect the string of the galvanometer from these stray charges which interfered with the electrocardiograms as well as endangered the safety of the string itself. This was successfully done by grounding the subject by means of the third electrode, *G* in figure 26, worn on the lower chest and connected to an iron water-pipe outside the chamber. This arrangement had previously been found more satisfactory than grounding the treadmill or the string galvanometer and made it possible for the men to walk in ordinary shoes without further insulation.

A short branch line connected by a double-pole double-throw switch, easily accessible to the operator, allowed either the subject walking on

the treadmill in the chamber or a second subject resting in an adjoining room to be in circuit with the string galvanometer. In this way electrocardiograms could be taken alternately from two subjects with but little loss of time.

As a rule the pulse was recorded photographically for a period of 15 to 20 seconds, first while the subject was sitting in an adjoining room, then while standing either in the adjoining room or on the treadmill before the walking started, and again at the end of the first, sixth, twelfth, and twenty-fourth minutes of walking. During the walking periods of January 28 and February 3 a visual pulse count was also made each minute by observing the deflections of the string for 15 to 20 seconds. A record of the pulse-rate was thus secured on these two dates for each minute of walking, either by the photographic method or by visual count with the aid of a stop watch.

In the experiments of January 28 and February 3, electrocardiograms were also secured of the pulse at the time of transition from standing to walking at the start, and again from walking to standing at the close of the period. As a rule these transition records consisted of 15 seconds of the first stage and 60 and 30 seconds of the final stage of the transition. A reproduction of a typical group of records for one subject is shown in figure 16. Finally the radial pulse was counted after the walking had ceased and the subject had been sitting quietly for 4 and 8 minutes.

For the records taken during sitting, standing, walking, and sitting after walking, the counts were in terms of pulse-rate per minute. In the transitional pulse records the individual pulse cycles were measured, as was done with the electrocardiograms during short periods of exertion described on page 151.

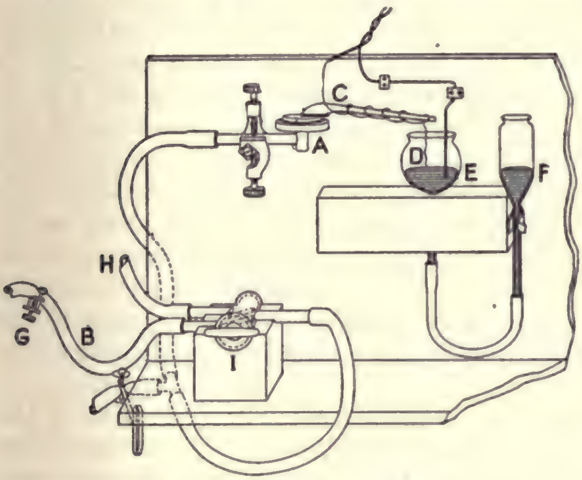
RESPIRATION-RATE.

A pneumograph worn by the subject around the lower chest was connected to a tambour, shown at *A* in figure 17, by means of a rubber tubing, *B*, which left the chamber by a brass tube in the rear of the skirt-wall. On one radius of the diaphragm of the tambour was cemented a light aluminum lever, *C*, the base of which pivoted on the edge of the tambour which was segmented at this point.[1] Supported by this lever a fine copper wire, *D*, dipped in a cup of mercury, *E*. Each respiration, acting through the pneumograph and tambour, made a contact between the wire and the mercury and operated a signal magnet placed in front of the camera used for the electrocardiograms. Adjustment of the contact in the mercury cup was made by means of the reservoir, *F*, while a screw pinchcock, *G*, on the tube from the pneumograph damped the movements of the lever. The apparatus was so

[1] A similar form of tambour making use of the principle of Frank's segmented capsule is illustrated by Wiggers, Circulation in Health and Disease, Philadelphia, 1915. See figure 11, page 57.

designed that if desired a second subject might be alternately connected to the tambour by means of a second tube, *H*, and the 3-way cock, *I*.

When the subject entered the treadmill chamber the pneumograph was connected to the tube in the rear of the skirt-wall and the proper adjustment of the reservoir made so that the hair wire opened and closed the circuit with each respiration. This actuated the signal magnet in front of the camera of the string galvanometer so that each time the pulse was photographed a record of the respiration was also secured on the same photographic film. A typical section of such a record is given in figure 16, in which the time in two seconds and fifths of a second, the pulse, respirations, and steps are shown.



The subject on the treadmill wore a pneumograph which was connected to a segmented tambour *A* by means of the rubber tubing *B*; with each respiration the tambour caused the aluminum lever *C* to complete an electric circuit through the fine wire *D* and the cup of mercury *E*. This circuit operated a signal magnet not shown in the figure. *F*, mercury reservoir for adjusting the level of the mercury in the cup *E*; *G*, pinchcock for damping the movement of the tambour; *H*, a duplicate of *B* for use with a second subject; *I*, 3-way stopcock for throwing either *B* or *H* into connection with the tambour.

FIG. 17.—Respiration recorder.

BLOOD PRESSURE FOLLOWING WALKING.

Determination of the blood pressure by any of the various sphygmomanometers is exceedingly difficult during walking, since the sway of the body, jar of the step, etc., all tend to make the readings uncertain. Moreover, in these walking experiments the fact that the subject was in a closed chamber precluded any thought of such an attempt during the actual period. The only determinations feasible under these conditions were records of the blood pressure shortly before and immediately after walking, the latter continuing several minutes to note any changes in pressure as the stimulus from walking decreased.

The pressure was therefore taken with a Tycos sphygmomanometer immediately at the close of the standing metabolism experiment. The subject wore the cuff in place on his arm during the time he was walking in the chamber. At the close of the walking period the chamber cover was lifted, and while the subject was still walking the cuff was inflated. The treadmill was then stopped. The systolic and

diastolic pressures were taken in rapid succession during the next two minutes which usually resulted in readings being secured at 15 seconds, 1, 1½, and 2 minutes after walking ceased. The subject then stepped off the treadmill, was weighed, and after sitting quietly in an adjoining room the pressures were again read on the fifth and ninth minutes after walking.

ROUTINE OF WALKING EXPERIMENT.

The general routine of the treadmill experiments was as follows:

On the completion of the measurements of the standing metabolism, which were conducted in an adjoining room on the portable respiration apparatus, the blood pressure of the subject was measured and the body electrodes were applied. The subject then came to the treadmill room, where these body electrodes were plugged into one branch of the leads connecting with the string galvanometer. During the 5 to 10 minutes that the subject was sitting quietly a photographic record was taken of his pulse by the string galvanometer. The subject then stood and after 5 to 10 minutes his standing pulse was again recorded by the string galvanometer. As soon thereafter as conditions permitted he entered the chamber. On his entering, the respiration pneumograph, which had been placed around his waist, was connected to the special tambour, the body electrodes were plugged into the branch of the galvanometer line extending to the chamber and the step counter was fastened to his ankle.

The subject stood quietly on the treadmill with the cover of the chamber lifted to its full height, which brought his head just inside the base of the cover. During this time the three fans in the chamber were running and the 15-cm. blower was delivering air over the side of the skirt into the chamber at its full capacity of 12 cubic meters per minute.

The assistant at the observer's table recorded the readings of the various counters and gave a warning of 15 seconds to the other assistants before the starting of the treadmill. In the experiments of January 6 the first walking pulse taken with the string galvanometer was at the end of the first full minute. In the experiments of January 28 and February 3 a photographic record was taken of the pulse at the time of the transition from standing to walking, which gave the pulse for the last 15 seconds of standing and continuing through the first full minute of walking. After 2 minutes of walking the large blower was stopped and wheeled back from the edge of the chamber. At the end of 2½ minutes[1] of walking the cover was lowered into its seal and the connecting pipe in the circuit from the drier to the rear of the chamber (*L* in fig. 14) was put in place; the chamber was now completely sealed. By this

[1] On January 6 the cover was lowered directly after the subject entered the chamber.

time the assistant had adjusted the mill to a speed of 70 meters per minute. At the end of $3\frac{1}{2}$ minutes of walking one assistant read the psychrometer; at the end of $3\frac{3}{4}$ minutes a second assistant read the level of the spirometer bell and a third balanced the Wheatstone bridge of the resistance-thermometer circuit. At the end of exactly 4 minutes of walking[1] which marked the beginning of the period proper, the temperature was taken and the air blowing through the drying circuit was stopped. Air samples were then drawn into the two Haldane gas-analysis apparatus with the necessary precautions. As soon as this was completed the air was again started in the drying circuit, and the analysis of the air proceeded forthwith.

As it was impossible for the assistant to read both step and distance counters at the same moment, it was the practice to read the step counter 10 seconds before and the distance counter 10 seconds after the 4-minute signal. As this was done at the 4, 14 and 24 minute readings, the elapsed time was the same, namely, 10 minutes in each instance, for the experimental period proper. The barometer was read as soon after the 4-minute signal as possible. During the next 10 minutes the assistants were occupied in watching the psychrometer, temperature, counters, and especially the spirometer bell, which rose with the temperature of the chamber as the experiment progressed. The temperature was controlled by means of electric fans blowing over the chamber and by opening the windows of the room. On account of the large radiating surface of the chamber and the thorough stirring of the chamber air, any tendency of the air to expand unduly could be quickly checked in this way.

At the close of 6 and 12 minutes of walking photographic records of the pulse were made. As stated earlier, the photographic record thus secured includes also records of the step and respiration rates. During the interval when the pulse was not being photographically recorded the operator made a visual count of the deflections of the string for 15 to 20 seconds each minute. By this means and the aid of a stop-watch records were secured for each minute. At $9\frac{1}{2}$ minutes after the period began, which was $13\frac{1}{2}$ minutes after the walking began, a reading was taken of the psychrometer; the spirometer was read at $9\frac{3}{4}$ minutes after the beginning of the period; and at 10 minutes gas samples were drawn, and the temperature, barometer, and counters were read in the same way as at the beginning of the period on the fourth minute of walking. This marked the end of the first half of the period, and these data were taken as a control and possible check should anything irregular appear later in the experiment.

[1] These 4 minutes of walking were looked upon as a period during which the carbon-dioxide production would have reached a uniform rate. That 4 minutes is sufficient for the purpose is indicated by the fact that both the pulse and respiration rates are fairly uniform by the fourth minute of walking; furthermore, unpublished results of experiments made in the Nutrition Laboratory show that the rate of oxygen consumption when a person walks at 30 per cent grade at a rate of 50 meters per minute becomes uniform by the end of the second minute.

The walking then continued without interruption for another 10 minutes, when the same procedure was followed, except that at this time a sample of air was likewise drawn into the Sondén gas-analysis apparatus for the determination of the oxygen present at the end of the experiment. At this time a photographic record of the pulse was again made. The walking continued until the samples of the air were drawn, when the cover of the chamber was lifted and pressure was put upon the cuff of the sphygmomanometer. At this point the treadmill was stopped and the blood pressure was determined as rapidly as possible during the next 2 minutes. The subject was then disconnected from the respiration tambour, galvanometer leads, and step counter. On leaving the chamber he was weighed and the final records of blood pressure and radial pulse were made in an adjoining room.

At the conclusion of the experiment the large ventilating fan was moved up to the chamber, the windows were opened, and both the room and chamber were given a thorough ventilation during the following 10 to 12 minutes. During this time preparations were made for the next experiment.

METHOD OF CALCULATING RESULTS OF THE METABOLISM EXPERIMENTS DURING WALKING.

The calculation of the carbon dioxide produced was a relatively simple matter. The apparent volume of the chamber was corrected for any change in the level of the spirometer, this correction being 21.5 c.c. for each millimeter of change. From this volume was deducted the air displaced by the subject, which was taken as the equivalent in liters of his body-weight. The corrected volume was then reduced to 0° C. and 760 mm. of pressure. The percentage of carbon dioxide as found by analysis and the corrected volume of the air in the chamber gave the total volume of carbon dioxide present at the start; a similar calculation gave the volume of carbon dioxide present at the end and the difference between the amounts, divided by the time elapsed, gave the carbon dioxide produced per minute.

The calculation of the oxygen consumed was not so simple, because, as stated elsewhere, the time available for each subject was limited to approximately 45 minutes, which precluded a determination with the Sondén gas-analysis apparatus of the oxygen present at both the beginning and end of the experiment. The oxygen present in the chamber at the start was obtained by computation as follows:

It was assumed that the respiratory quotients of the normal subjects would be approximately 0.85; those of the men on the restricted diet were found to be more nearly 0.81. It was also assumed that the air in the chamber before the cover was lowered was practically of the same composition as outdoor air, this being due to the open windows and complete ventilation of the chamber and room. The percentage

of oxygen consumed from the chamber during this preliminary period would therefore be in the following ratio:

Per cent CO_2 found : per cent O_2 consumed :: R. Q. : 1

Deducting this calculated percentage of oxygen consumed from the percentage of oxygen in outdoor air would give the percentage of oxygen present in the chamber at the beginning of the period, subject to a correction for change in the volume of air in the chamber due to the fact that more oxygen has been consumed than carbon dioxide has been produced. Of the original air 100 volumes were composed as follows: O_2, 20.932;[1] CO_2, 0.031; N_2, 79.037; total, 100.000. The altered volume is composed of 79.037 parts of unchanged nitrogen plus an increased amount of carbon dioxide, and a decreased amount of oxygen, the total being less than 100. The true percentage of oxygen would

TABLE 6.—*Records of metabolism experiment, with subject walking in treadmill chamber.*

Subject: *Gul.* Date, Feb. 3, 1918. Weight with clothes, 64 kg. Experiment began 7^h18^m a. m.

Minutes of walking.	Reading of distance counter.	Reading of step counter.	Psychrometer.			Spirometer.	Temperature.	Barometer.	Carbon dioxide by Haldane.		Oxygen and carbon dioxide by Sondén.
			Wet bulb.	Dry bulb.	Aqueous tension.				1	2	
			°C.	°C.	mm. Hg.	mm.	°C.	mm.	p. ct.	p. ct.	p. ct.
Start	5,945	9,521									
3 min. 30 sec.			15.20	21.70	8.9						
3 min. 45 sec.						+75					
4 min. 00 sec. (start of period.)	6,160	9,783					21.00	764.63	0.141	0.145	
13 min. 30 sec.			15.30	20.95	9.5						
13 min. 45 sec.						+40					
14 min. 00 sec.	6,682	10,380					20.63	764.63	.422	.439	
23 min. 30 sec.			15.25	21.00	9.4						
23 min. 45 sec.						+116					
24 min. 00 sec. (end)	7,207	11,006					20.56	764.48	.704	.708	20.872

therefore be larger in the proportion as the altered volume is to 100. From this corrected percentage and the volume of air in the chamber, the amount of oxygen present at the start is computed. The analysis of the air by the Sondén gas-analysis apparatus at the end of the experiment gave the combined percentage of oxygen and carbon dioxide, from which the percentage of oxygen was found by deducting the percentage of carbon dioxide as determined simultaneously on the two Haldane gas-analysis apparatus. The difference between the volume of oxygen present at the start and at the end, divided by the time, gave the oxygen consumed per minute. The data and calculations of a typical experiment are shown in tables 6 and 7.

[1] Benedict, Carnegie Inst. Wash. Pub. No. 166, 1912, p. 114.

TABLE 7.—*Calculation of metabolism experiment with Gul walking in treadmill chamber, Feb. 3, 1918.*

CALCULATION OF CARBON DIOXIDE PRODUCED.

(*a*) *Carbon dioxide present at start of period:*

		Liters.
Apparent volume of chamber		2,419
Correction for spirometer, 75 mm. ×21.5 c.c.		1.61
		2,420.61
Volume of subject		64.00
Total volume		2,356.61
Log. volume, 2,356.61	=3.37229	
" temperature 21.0 reduced to 0° C.	9.96776–10	
" barometer, corr.[1] 755.73 reduced to 760 mm.	9.99756–10	
" corr. volume	3.33761 =	2,175.8 liters.
" per cent CO_2 at start 0.143	7.15534–10	
" CO_2 at start	0.49295 =	3.11 liters.

(*b*) *Carbon dioxide present at end of period:*

		Liters.
Apparent volume of chamber		2,419
Correction for spirometer, 116 mm. ×21.5		2.49
		2,421.49
Volume of subject		64.00
Total volume		2,357.49
Log. volume, 2,357.49	=3.37245	
" temperature 20.56 reduced to 0° C.	9.96841–10	
" barometer, corr.[1] 755.08 reduced to 760 mm.	9.99718–10	
" corr. volume	3.33804 =	2,177.9 liters.
" per cent CO_2, 0.706	7.84880–10	
" CO_2 at end	1.18684 =	15.38 liters.

	Liters.
Vol. CO_2 at end	15.38
Vol. CO_2 at start	3.11
Vol. CO_2 produced	12.27

Duration of period, 20 minutes. CO_2 produced per minute, 614 c.c.

CALCULATION OF OXYGEN CONSUMED.

(*a*) *Oxygen present at start of period:*

Total per cent CO_2 in chamber at start	0.143
Assumed per cent CO_2 in original (outdoor) air in chamber	.030
Per cent CO_2 produced at expense of the oxygen originally present in chamber	.113

$$\text{Per cent oxygen deficit} = \frac{\text{per cent } CO_2 \text{ produced}}{\text{R. Q. (assumed)}} = \frac{0.113}{0.81} = 0.140$$

Per cent of O_2 in outdoor CO_2-containing air	[2]20.932
Per cent of O_2 deficit in chamber air	.140
Apparent per cent of O_2 in chamber air	20.792

100 volumes of the air originally in the chamber, assumed to be of outdoor composition, would consist of 20.932 volumes O_2; 0.031 volume CO_2; and 79.037 volumes N_2; total, 100.000 volumes; but since there has been a diminution in the volume in the chamber due to the fact that more

[1] Observed barometer minus corrections for barometer temperature (brass scale) and aqueous tension.

[2] The oxygen in the air on a CO_2-free basis = 20.938 per cent; carbon dioxide = 0.031 per cent. (Benedict, Carnegie Inst. Wash. Pub. No. 166, 1912, p. 114.)

oxygen has been consumed than carbon dioxide has been formed, and since the volume of nitrogen is unchanged, it is evident that at the start of the period these 100 volumes are altered to the following: N_2 (unchanged), 79.037 volumes; CO_2 (by analysis), 0.143 volume; O_2 (by computation above), 20.792 volumes; total, 99.972 volumes, of which the percentage of oxygen would be

$$\frac{20.792}{99.972}\times 100=20.798$$

The correct percentage of oxygen at the start is therefore 20.798.

Volume of chamber at 0°, 760 mm. at start was 2,175.8 liters

Log. volume of chamber at start of period 2,175.8.....	=3.33761
" per cent O_2, 20.798..........................	9.31801–10
" oxygen present at start........................	2.65562 =452.50 liters.

(b) *Oxygen present at end of period:*

By analysis with Sondén apparatus, per cent O_2+CO_2...........	=20.872
By analysis with Haldane apparatus, per cent CO_2..............	.706
Per cent oxygen present at end of period................	20.166

Log. volume of chamber 0°, 760 mm., at end of period, 2,177.9....................................	=3.33804
Log. per cent oxygen at end 20.166............	9.30462–10
Log. volume oxygen at end of period..........	2.64266 =439.20 liters.

	Liters.
Oxygen present at start of period.............................	452.50
Oxygen present at end of period..............................	439.20
Oxygen consumed....................................	13.30

Duration, 20 minutes.

Oxygen consumed per minute, 665 c.c.

Respiratory quotient, $\frac{CO_2}{O_2}=\frac{614}{665}=0.92$.

1,000 c.c. CO_2 at respiratory quotient of 0.92 =5.378 cals.;[1] *e. g.*, 614 c.c. =3.30 cals.

PSYCHOLOGICAL PROGRAM AND TECHNIQUE.

The measurements of the neuro-muscular processes and the general mental condition of the men in Squads A and B were made at the Nutrition Laboratory when the men were in Boston, Saturday evenings and Sunday mornings. This arrangement of bringing the squads to Boston was a particularly advantageous one for the psychological phase of this research, as it made possible the securing of a maximum amount of data in the time at our disposal, with the least interference with the college duties of the subjects. Moreover, by doing this part of the work at the Nutrition Laboratory conditions were obtained which were more suitable and uniform throughout the experimentation than they would probably have been elsewhere. The students were away from their usual college environment, with its numerous interests and distractions. The college work for the week was completed. Since the men were all present and had no other duties or engagements than to serve as subjects in the psychological and other measurements, it was unnecessary to make individual appointments for an experimental session, a condition which unavoidably gives rise

[1] Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, p. 29.

to many irregularities. All of the men in one squad could thus be measured on one day within a period of 4 hours and following the ingestion of a standard meal which was uniform for each time they were present. (See p. 262.) Physical activity during the hours preceding the evening session was also made uniform by the necessity of the railroad journey from Springfield to Boston.

At the Nutrition Laboratory certain apparatus and techniques were available which, under the circumstances, could not well have been transferred to Springfield. Early in September, as has been explained previously (see p. 44), there was considerable doubt as to the possibilities in the experiment. The enrollment at the college was small and many of the older students would probably be called for Government service. It was of course impossible to know whether the students would volunteer as subjects, and, if so, how many would be available for the experiment. Furthermore, as in the preliminary plans it was thought desirable to continue the experiment only to the Christmas vacation, it was necessary that when college did open, the experiment, if it was to be started, should begin immediately. By coming to the Nutrition Laboratory for the psychological measurements the greater part of the apparatus would be in readiness and thus a minimum of experimental opportunity would be lost. Some of the apparatus and technique had been previously elaborated in connection with other problems with the object of securing measurements and procedures which could be repeated on the same individual without the development of large practice changes. Great care had been taken to make the measurements as objective and free from personal bias as possible. Many of them will be noted to have a distinct physiological trend. The avoidance of all practice changes with fluctuations in interest and attention is of course an ideal which is never quite reached in psychological investigations, but it is believed that the measurements, procedures, and conditions in the present research all contributed to minimizing the influence of these factors. The interval of two weeks which came between experimental sessions of the same squad was also useful for this purpose.

In planning this phase of the investigation there were several considerations which favored the use of a wide range of neuro-muscular measurements. The nature and extent of the effects of prolonged reduced diet could not be anticipated, and for this reason these effects should be given as many opportunities as practicable to show themselves. Our men were not what might be termed trained psychological subjects; they had received but slight practice in introspection. The tests were given in the evening. Under these conditions prolonged measurements of one kind would have favored development of sleepiness and fatigue. The physical movements and frequent changes necessitated by the large variety of measurements prevented ennui.

A serious effort was made to secure sufficient data for every measurement with each subject to obtain a fair sample of the subject's performance. Usually not more than 10 to 12 minutes was required for any one measurement, while certain of the measurements required a period of only 5 minutes or even less. Under normal circumstances this is not sufficient to cause ennui or fatigue.

The large variety of measurements made possible the employment of several men at the same time. Not infrequently a man may have some physical limitation which makes one or more of the measurements difficult or unpleasant to him. For example, he may have poor eyes, the knee-jerk may be absent, or he may believe that his memory is very poor. Such circumstances favor short intensive tests and several of them.

PSYCHOLOGICAL MEASUREMENTS USED.

The measurements which were chosen for this investigation may be catalogued under two heads:

First, those given to the men as a group, that is, when all the men served as subjects at the same time, at the beginning of each evening session. These, listed more or less in their order of complexity, were:

(1) Accuracy in tracing between irregular parallel lines.
(2) Discrimination for the pitch of tones.
(3) Discrimination for specified number groups on a printed page.
(4) Addition of one-place numbers for a period of 10 minutes.
(5) Memory span for 4-letter English words.

Second, measurements given to the men individually; that is, when one man was tested at a time. These, numbered serially from the measurements previously given and listed in approximate order of increasing complexity, were:

(6) Strength of grip (evening and morning).
(7) Changes in pulse rate occasioned by short periods of exertion (morning).
(8) Latency, amplitude, and refractory period of the patellar reflex.
(9) Reaction time for turning the eye to a new point of regard (morning).
(10) Reaction time for speaking 4-letter words.
(11) Continuous discrimination and reaction in finding serial numbers.
(12) Sensory threshold for visual efficiency (acuity).
(13) Sensory threshold for electric shock.
(14) Speed of the eye movements (morning).
(15) Speed of the finger movements (evening and morning).
(16) Efficiency in traversing a right-angle maze.
(17) Efficiency in performing certain clerical tasks.

MEASUREMENTS BY THE GROUP METHOD.

The group method was useful in this research, not only because it made possible a material saving in the time of the subjects, but it

required all of the men to be on time; it provided a suitable occasion for announcements and general instructions in procedure, and it also gave a period for quiet work and adjustment of mental attitude before the individual measurements were begun. Immediately after the standard evening meal (see p. 59) in a nearby restaurant, the men came to the Nutrition Laboratory. The group tests were made in the library. This room is 16 by 27 feet, with ceiling 11 feet high, and was well suited for a group experiment with a squad of 12 men; the lighting was direct from three clusters at the ceiling arranged lengthwise of the table. These clusters were supplied with Mazda and nitrogen-filled lamps and no one complained of the lighting at any time except *Can*, whose eyes were rather weak and who thought the light was too brilliant. The table at which the men worked was 16 feet long and 4 feet wide; no objects other than the pencils and the paper blanks to be used by the subjects were on the table. The men were arranged 6 on either side of the table. At the first session seats were assigned and each man occupied his particular seat at the subsequent sessions when he was present, although it was not believed that one location in the room was more favorable than another for the group experiments. A considerable period was allowed for preliminary adjustments, announcements, questions, and a general quieting of the men before beginning the evening session. In the following paragraphs the measurements given by the group method will be described in the order in which they were used each evening. This order was never varied.

(1) Accuracy in Tracing Between Irregular Parallel Lines.

In such a test, in which the subject has but a narrow space within which he must mark to avoid contact with printed lines, the pencil with which the record is made is naturally of importance. It should be fairly hard and well pointed, but not so sharp as to break on slight pressure or to catch in the paper. Each subject was provided with two long No. 3 pencils, which were carefully pointed. In the sharpener used for this purpose, the tip of the pencil lead finally came to rest against a member between the two cutters and thus indicated by pressure, to the one who was doing the sharpening, that sufficient grinding had been done, since no more wood can be removed from the pencil without crushing the point already made. The points made with this type of sharpener are uniform and satisfactory.

The form of the blank used can be easily understood from inspection of figure 18.[1] This particular blank was filled in with a pen for illustration. The open space between the parallel lines is 2 mm. wide; the straight lines of which the maze is composed are each 10 mm. in length.

[1] This form of motor test was described and figured by Whitley, Archives of Psychology (Columbia Contributions to Philosophy and Psychology), 1911, **20**, p. 87 ff. Dr. Whitley measured the total time to complete the task, adding to the score 5 seconds for each touch error.

Each course is made up of 28 of these straight lines. The test blank was properly dated and placed face down on the table before the subject, who entered his name prior to the test. A metronome was arranged to beat half seconds, that is, 120 beats per minute. The instructions to the subject were to draw in the open space a light continuous line, without touching the printed parallel lines, to synchronize his movements with the beat of the metronome, making one straight line for each beat, and to make the movements with the muscles of fingers and hand, that is, to avoid whole-arm movement. "Avoid contact with the line; keep up with the metronome," were the points stressed before beginning the task. When the blank was in position and the pencil on the proper point for starting, the metronome was

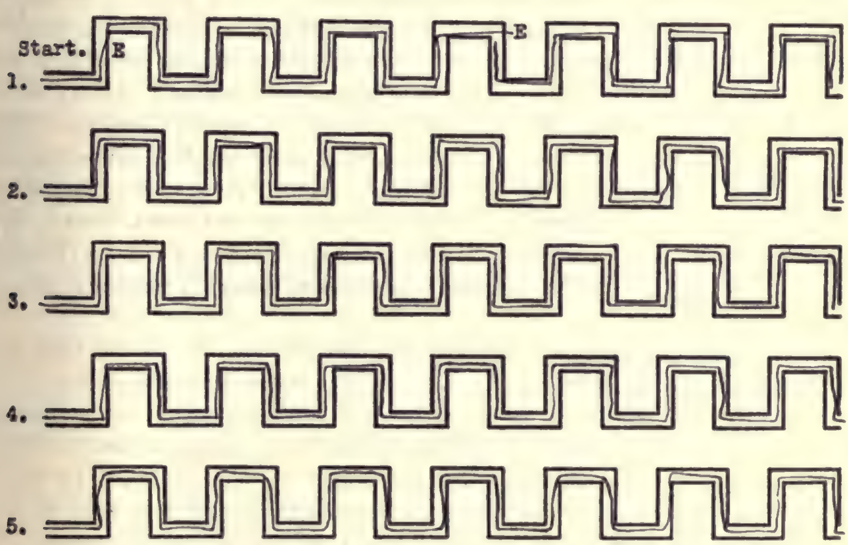


FIG. 18.—Specimen record for accuracy in tracing between irregular parallel lines.

Two of the errors are marked with *E*. The movements were in tempo with a metronome beating half seconds, and to trace each course should require just 28 beats (14 seconds).

released. The experimenter counted audibly with the metronome, "one, two, ready, go," counted silently 27 beats, and on the twenty-eighth beat called "stop." At that moment the pencils were immediately lifted from the paper. Between trials 3 and 4 a half-minute intermission was allowed, during which the men were encouraged to shift position.

In scoring the record, one error was counted for each contact with a boundary-line, and if the subject did not finish in tempo with the metronome, an error was counted for each beat that he was found behind. The tracing required about 4 minutes. The blanks were immediately turned face down at the last "stop" signal.

(5) Memory Span for 4-letter English Words.

In planning for this memory test, it could not be known how little or how much practice the men might have had in such procedures, or whether any of them were familiar with the device of fitting words together into a story for purposes of recall. This latter is a more or less common parlor game. It was therefore thought best to give a list of words which was long enough to be far above the memory span of the ordinary individual and, indeed, so long as to make the story method of recall difficult to use. Thus it was not practicable to have the words recorded in reference to the position given them in the list or to treat the results in some of the more elaborate ways which have been used in memory experiments.[1] Eight series or lists, each containing 25 one-syllable English words, each word composed of four letters, were prepared and used. For the most part the individual lists were distinctive. Occasionally one specific word was embodied in two lists, but these were not used in consecutive experimental sessions. Many of the words in these lists were the same as those selected and used by Dodge and Benedict in the memory experiments of their alcohol investigation and were later employed by one of us.[2] Since there were 10 sessions with Squad A, 2 of these 8 lists were given a second time, that is, list No. 1 was given on September 29 and January 26, list No. 2 on October 13 and February 2. With Squad B there were 8 experimental sessions, with no repetitions.

The words were read at the rate of 1 per second, in tempo with the metronome beating audibly to all. They were pronounced by the experimenter as distinctly as possible and without stress or grouping. The subjects were instructed to listen intently for immediate recall, to watch the lips of the one who was pronouncing the list, and to avoid whispered repetitions of the words. Immediately at the end of the pronouncing the subjects were to write on the back of the accuracy tracing blank as many of the words as could be recalled in 1½ minutes. In any extra time which a man might have at his disposal he was to give attention to the legibility of his writing. The subjects were told that with words pronounced alike and spelled differently either spelling was acceptable, provided the word written was of four letters. No instruction was given concerning the order in which the words were to be recorded and nothing was said about the matter of insertions, that is, words written by the subjects which were not included in the lists. This latter point was considered in planning the experiment, but it was thought that if the men knew they would be penalized for each insertion they made it would tend in some cases to inhibit their best performance. Since they were given definitely to

[1] Whipple, Manual of Mental and Physical Tests, part II, Baltimore, 1915, p. 166.
[2] Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 126; Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 67.

understand that they were to write only the words that they remembered, from the list which was pronounced, any other words written would be due to faulty recall or to the aim on the part of the subject to add a few extra words in the hope that he might chance upon some in the list. No instance of the latter sort is clearly demonstrated in the records. Occasionally, a subject having remembered the general sound of a word, put in two or three words consecutively which had that general sound complex, in the hope that one of these might be the exact word needed. Such special cases were given careful consideration. A word which sounded very nearly like one pronounced was given full credit. The subject may be credited one point for each word correctly recalled, and a statement of the number of errors given,[1] or his errors may be subtracted from the other score by deducting one point for each one.

6	2	4	5	4	4	4	5	6	7
5	5	7	9	7	8	6	7	2	9
8	6	5	4	4	3	3	9	9	6
7	8	9	8	5	9	5	2	6	4
7	3	6	2	7	6	8	4	5	9
4	8	8	9	6	2	3	8	6	7
9	8	5	6	6	4	5	3	3	5
8	7	8	3	8	9	6	9	5	9
3	3	3	8	9	2	2	8	9	8
6	8	2	3	4	8	6	2	7	6

FIG. 19.—A block of 100 digits arranged in 10 columns of 10 each, as in the material for addition work.

The type was 12-point and the figures are here reproduced full size. A page contained 8 such blocks of columns.

7	7	2	7	2	2	9	6	6	3	51
4	9	6	5	7	5	3	7	2	9	57
6	6	3	9	9	6	3	9	9	8	68
9	4	8	2	7	8	8	5	6	7	64
7	9	3	5	2	3	4	7	5	3	48
8	7	9	3	9	8	2	6	6	2	60
3	5	9	4	6	8	6	4	3	3	51
4	9	5	8	3	7	9	5	5	4	59
5	8	2	9	5	3	5	4	9	7	57
4	6	5	9	7	8	6	9	7	9	70
57	70	52	61	57	58	55	62	58	55	

FIG. 20.—One block of the addition material showing the sums properly entered for the vertical and horizontal columns.

The same material is used for a cancellation test in which the subject marks each pair of digits which when added equal 11, as described on page 145. One error of omission is found near the center of this block.

(4) ADDITION OF ONE-PLACE NUMBERS.

The blank for this test was specially prepared, as no printed form with which we were familiar entirely met our needs. In many of the printed forms available the print was not so legible as desirable. Furthermore, and what was especially important for this work, they did not provide enough material for several successive trials with the same subject to avoid the danger of some memorizing.

The subject should feel that he is adding new material; there will then be no tendency for him to try to remember distinctive combinations in certain columns and the sums for these columns. In an effort to meet our need, digits were arranged in blocks of 100. Figure 19 reproduces full size a portion of one of the blanks. The type was

[1] Simpson, Columbia Contributions to Education, No. 53, New York, 1912, p. 122.

12-point. The digits 1 and 0 were not employed, and an effort was made to avoid combinations which added to 10. Each digit was used with approximately the same frequency in the material taken as a whole, as is seen in figure 19, the blocks being arranged in 10 columns, each containing 10 digits. A page was composed of 8 of these blocks. Six different pages of such material were prepared.

The printed forms were set up on a linotype machine, each horizontal line of digits being a separate linotype slug. One hundred of these slugs were made up and numbered with a punch. They could thus be readily combined into an indefinite number of blocks of addition material. This method made a substantial saving in the cost of composition.

The procedure followed in the test was to begin adding the 10 vertical columns in the upper left-hand block of material, placing the sums below. When the 10 columns had been added, the subject added the same material, but in the horizontal lines, so a block of 100 digits in the form shown in figure 19 provided 20 lines of addition. The method of adding, and of entering the sums, is shown in figure 20. The subjects were told that they had 10 minutes for the addition. No clock or watch was visible and no warning signal given until the signal to stop. The time interval was measured with a stop-watch. The men were instructed to work as swiftly and accurately as possible. Equal emphasis, so nearly as may be judged, was placed on both factors. Particular attention was called to the most frequent types of errors in addition. The attention of the subject was also frequently directed to the ease with which numbers may be transposed in writing them down. The greatest care was taken to maintain silence in the room. The men worked on the honor principle, and without exception they worked in this adding test very silently and intensely (at least so far as could be judged from facial expressions and physical attitude).

There is no precedent at hand for using horizontal lines of digits in a test of adding efficiency. The method suggested itself as an economical expedient to minimize movements, such as shifting of paper and position. Preliminary trials with other subjects did not disclose any particular difficulties in adding digits arranged horizontally when the material was spaced as it is in figures 19 and 20. It must be noted that in printing from linotype slugs the horizontal columns always remain the same, a particular horizontal column being subject to shift from one block to another and to different position in a block of such digits, but the sum of it being always the same wherever it is. No information as to the method of makeup of the blanks was given the men. They never saw the forms except at the 10-minute test periods. They did not know how many different blanks existed, as these were designated from each other by a secret mark, which was the digit in the extreme lower left-hand corner. It is hardly likely that under these circum-

stances they would note that the horizontal columns were unchanging and would try to memorize them.[1]

Immediately at the close of the 10-minute period of addition, the blank was turned face down on the table in front of the subject, in the same position as before the signal was given to begin the test. The subject then took out his watch, laid it on the table, and made a pulse count on himself for a period of 30 seconds. He recorded this count on the back of the addition blank, under the date with his name.[2]

(3) Discrimination for Specified Number Groups on a Printed Page.

The addition blank served as the material for this test also. Each column of 10 digits was regarded as a unit, as if it were the only material on the page. Each and every combination of two successive numbers which, when added together, equaled 11, were to be canceled by drawing a line through them connecting the two.[3] Thus the combinations found would be: 2 and 9; 3 and 8; 4 and 7; 5 and 6; and the same in their reverse order. A group of numbers, such as 4, 7, 4, would be regarded as two such combinations and a line drawn through, connecting the three digits. Figure 20 shows a portion of a number cancellation record. The frequency of combinations of two successive digits equaling 11 is of course not the same in all blocks of digits, but as the 5-minute interval allowed for this test was sufficient for most of the subjects to cover several blocks of the material, this factor was neglected. The subjects were instructed to go over all the horizontal lines of the 8 blocks of material on the blank and to check each one of the desired combinations. Then the vertical columns were checked, beginning as before at the upper left-hand corner. Previous to each trial it was impressed upon the subjects that they must mark every combination equaling 11 and that they would be penalized for leaving unmarked any such combination in the material which they had gone over. Immediately at the end of the 5-minute interval allowed for this task, the blanks were taken up. In scoring the record the last combination mark was considered the limit of the material which they had covered.

(2) Discrimination for the Pitch of Tones.

Pitch discrimination is a measurement which can be easily given by the group method. A well-recognized standard form of procedure has

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[1] This possible difficulty could have easily been provided against, as the linotype slugs could have been cut, making them just half as long. Each slug would then have contained 5 digits and the number of possibilities for combinations into columns of 10 would have been almost infinite. This method will be followed in any subsequent printing from these same slugs.

[2] Several of the subjects in Squad A found considerable satisfaction in chewing gum. (See p. 266.) They were asked to remove the gum from the mouth during the addition test.

[3] It was first suggested to us by Professor H. S. Langfeld that we use the cancellation test in somewhat this form. Langfeld and Allport, An Elementary Laboratory Course in Psychology, Boston, 1916, p. 100. See also Burtt, Journ. Applied Psychol., 1917, **1**, p. 201.

been worked out by Seashore, and was used in the present case.[1] Suitable wooden resonators were provided. The tuning-forks were all originally A435 vd. in pitch.[2]

The pitch differences were produced by filing between the prongs, hence all of the steps were lower than the standard, *i. e.*, the one fork which had not been filed and which was A435 vd. The pitch intervals between the standard and the other nine forks were 1, 2, 3, 5, 8, 12, 17, 23, and 30 double vibrations (*vd.*), respectively. The experimenter who sounded the forks was completely out of view of the subjects, and the usual precautions were taken concerning noises and such things as could serve as secondary criteria. Care was also taken to make the intensity of the tones equal and of similar duration. A chance order for the presentation of the tones was worked out previous to the tests and followed. Preliminary trials were given and explanations made to arouse interest in pitch discrimination. By numerous trials it was explained to all the subjects that the judgment was to be made in reference to the last of a pair of tones, *i. e.*, he was to judge if the latter of any two tones was higher or lower than the former of the pair. A blank, ruled in centimeter squares, was provided, upon which these judgments could be recorded conveniently, the columns being lettered across the top and numbered down the side at the left. The upper left-hand corner of this blank is shown about full size in figure 21. The judgment for the first pair of tones is recorded in square A–1. This is given in the illustration as *H*, meaning that the second tone was judged higher than the first of the pair. The judgment for the second pair of tones is recorded in square B–1. In figure 21 it is given as *L*, meaning that the second tone was judged to be lower than the first. The particular square in which the judgment was to be recorded was called out in the first experiment and at the first of each experiment just before the pair of tones was given, so that the subject might have no doubt as to where to write his judgment. He was required to make a judgment of either higher or lower, that is, to fill in the appropriate square with either *H* or *L*, according as it sounded to him. There were no judgments of equality.

At the first session with each squad all the pairs of forks were used. This would give 9 pairs of tones for discrimination purposes. It was then discovered that in the case of both squads the pairs of tones, S–30, S–23, S–17, and S–12, were quite uniformly judged correctly. Therefore, it was necessary to use only the remaining pairs in succeeding sessions, that is, S–8, S–5, S–3, S–2, and S–1, or 5 pairs of tones. Really, the pair S–8 might also have been omitted, as the subjects were almost always correct with this judgment. However, some easy judgment is

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[1] Seashore, Report of the Committee of the American Psychological Association on the Standardizing of Procedure in Experimental Tests, Psychological Monograph, 1910, **13**, p. 21.

[2] The tuning-forks were those listed as No. 1730 in the catalogue of C. H. Stoelting Co., Chicago.

a great help in steadying the subject and giving him a feeling of sureness, so this interval was retained. The pairs were regularly given in order of difficulty, *i. e.*, proceeding from S–8 to S–1, and the judgments were marked in sequence on horizontal lines in the blank forms. Thus: S–8 was marked in square A–1, and S-1 in square E–1. Thirty judgments with each interval or 150 judgments in all constituted the test.

After 100 of the pitch-discrimination judgments had been given, a short intermission was taken, during which the subjects made a pulse count on themselves, recording the same on the back of the pitch-discrimination blank. Immediately after the last pitch-discrimination judgment had been made, the blanks, which had been dated, and signed, were collected and the men were assigned to their next duties.

	A	B	C	D	E	F	G	H	I	J	K
1	H	L	H	H	~~L~~		L	H	L	H	~~L~~
2	L	L	H	H	L		L	L	H	L	H
3	H	L	H	H	~~H~~		H	H	L	~~L~~	H
4	H	H	L	L	H		H	H	L	H	L
5	L	L	H	L	L		L	H	L	H	~~H~~

FIG. 21.—A portion of a pitch discrimination record.

Each square filled in with *H* or *L* represents a judgment on a pair of tones. Sometimes the subject was in error, as is indicated by the diagonal lines. In columns *A* and *G* the tones presented were S–8. This was the easiest pair to judge. The most difficult pair was S–1 (see columns *E* and *K*).

MEASUREMENTS BY THE INDIVIDUAL METHOD.

The pitch-discrimination test was the last test in the group series. At its conclusion, and after the measurement of the skin temperature (see p. 249), four of the men were sent downstairs for individual psychological measurements. The remaining subjects were employed for the Du Bois body measurements, the blood test, practice in becoming used to walking on the treadmill, etc. (see program as outlined on p. 59), until the experimenters were to use them.

The psychological apparatus was distributed in three rooms, which open from a common hallway. With the aid of two assistants, it was possible to make such measurements with four of our subjects at the same time, each man serving a total of about 70 minutes. The measurements were grouped in the different rooms, according to expediency. In room A were located Nos. 6, 11, 16, and 17 (strength of

grip; continuous discrimination in finding serial numbers; efficiency in traversing the maze; and the clerical tasks). In these tests two men could work in the same room at the same time without disturbing each other. The subjects were located at two well-lighted tables placed some distance apart and not facing each other. The assistant, Mr. J. I. Waldron, whose careful service we were fortunately able to secure, occupied a position between them. The working conditions were made satisfactory to the men. One subject filled out the clerical test blank while the other completed tests Nos. 11 and 16. The time required for each subject to do his particular task was recorded by the assistant in seconds and fractions on a suitable form. The men then exchanged position and tasks. The strength of grip was usually taken after the other tests in room A were completed, and frequently one subject looked on while another subject was being tested. Each subject made a pulse count on himself when he had completed the clerical blank.

Room B contained measurements Nos. 8, 10, and 15 (patellar reflex, word reactions, and finger movements). The general set-up for these three measurements is shown in figure 31, p. 160. They formed a convenient group, since they all relied on the Blix-Sandström kymograph for chronographic record. The experimenter tested the subjects individually. The word reactions were always given as the first test, this being followed by the three finger-movement records. Between the finger-movement records there was an interval of one minute. In the first interval the subject was asked for any observations concerning his general condition. In the second interval, or that between the second and third finger-movement records, a pulse count was taken by the experimenter at the wrist. Following the last finger-movement record, the subject changed chairs and reclined in a steamer chair for the patellar reflex measurement, following which a second pulse count was made by the experimenter. The time required to complete the tests in room B was from 17 to 20 minutes. The subject was then sent to room A or C, if he had not previously had the measurements in these places.

In room C, which is the main psychological laboratory, measurements Nos. 12 and 13 were given. The threshold for electric shock was always first and that for visual efficiency came second. There was a shift of position and a slight intermission between the measurements and 8 to 10 minutes devoted to each one. There were, of course, individual differences, and it was not possible to take exactly the same amount of data on each man. When the measurements had been completed or the time interval allowed had elapsed, the subject was sent to another room or upstairs.[1] The two measurements were taken by Mr.

[1] Some latitude in time for testing a particular man was naturally allowed, but in general, a serious effort was made to maintain a schedule, as it was only on this basis that it was possible to test 12 men in such a variety of ways within a period of 3 to 3½ hours.

Edward S. Mills, whose thorough understanding of the apparatus and intelligent cooperation as assistant in psychological investigations during the last few years insured care in execution.

The measurements made by the group method and the three series of individual measurements just outlined made up the evening psychological session. No effort was made to have the men serve as subjects in identical order each evening, nor was it expedient to give tests in the same order to the individual subjects each evening.

In addition to the measurements made in the evening, a number of tests were made in the morning after the subjects had spent the night in the group respiration chamber. At these morning sessions, also, the subjects were taken in an order which was most convenient to themselves. The distinctive measurements for the morning session were: Nos. 7, 9, and 14, that is, changes in pulse rate with exertion, reaction time of the eye, and speed of eye movement. These were all in room C, and required the attention of an experimenter and an assistant, Mr. Mills. Finger-movement records, pulse counts, and strength of grip records were taken by a second assistant, Mr. Waldron, in room B. The subjects were called, dressed, ate their breakfast, and came to be tested in groups of 3. It required about 20 to 25 minutes for each group. A particular subject began with room B or C, as was convenient for the experimenter. One subject served at a time in room B, two were tested simultaneously in room C—one for the pulse measurements and the other for the eye measurements. The first subjects were ready at 6^h30^m a. m. When they had completed the measurements at about 7 a. m., they left the Laboratory not to return until the next session, usually two weeks later. The last subjects tested were ready to leave the Laboratory about 8^h30^m a. m.

The individual measurements as distributed between the evening and the morning sessions and in the three rooms are therefore as follows:

Evening:

Room A.

6. Strength of grip.
11. Continuous discrimination and reaction in finding serial numbers.
16. Efficiency in traversing a right-angle maze.
17. Efficiency in performing certain clerical tasks.

Room B.

8. Latency, amplitude, and refractory period of patellar reflex.
10. Reaction time for speaking 4-letter words.
15. Speed of the finger movements.

Room C.

12. Sensory threshold for visual efficiency.
13. Sensory threshold for electric shock.

Morning:

Room C.

7. Changes in pulse-rate occasioned by short periods of exertion.
9. Reaction time for turning the eye to a new point of regard.
14. Speed of the eye movements.

Room B.

15. Speed of the finger movements.
6. Strength of grip.

On the three mornings when walking experiments were made, *i. e.*, January 6 and 28 and February 3, the morning psychological program was omitted, with the exception of strength of grip. This was taken after 5 minutes of sitting following the walking on the treadmill. The regular morning measurements were also omitted on December 20, when the time was given over to taking standard electrocardiograms. (See p. 393.)

A detailed description of the technique and procedure for the measurements used by the individual method is given in the following pages. The measurements are numbered serially, as on page 139, and treated in an order which represents their general increasing complexity.

(6) Strength of Grip.

The instrument commonly known as "improved form of Smedley's dynamometer" was used in this test.[1] The handles of the instrument were adjusted to a span of 5.5 cm. and were kept constant at this distance with all the subjects. The subjects as a group and individually were given full instructions in the use of the dynamometer. They stood erect and free from other support; the instrument was held down at the side of the thigh, not against the leg, and dial outward.[2] Five trials were made with each hand alternately. There was an interval of about 10 seconds between trials, during which the assistant read the instrument and set the indicating hand at zero. Immediately after the grip the subject called "right" or "left," as the case might be, and held out the instrument to the assistant to be read. The assistant did not call out the reading, but entered it in a form provided for the purpose. No particular effort was made to stimulate the subject, although before he began he was told to do his best. Usually someone else besides the assistant was present and watching him. Although no opportunity was given the subject to read the record on the dial carefully, he knew in a general way, from the position of the indicator, about what score he was making, and might be able to remember his performance from time to time, but no information was given him.

The particular instrument which was used was tested against standard weights to find if any corrections should be made in the reading.[3] The results of these standard tests are shown in table 8. Two sets of readings were taken, that is, under temperature conditions of 25° C. and 13.5° C. The table is divided accordingly; there is a column for standard weights; one for the average reading from five entirely independent trials, and the average error, plus or minus, between the read-

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[1] This instrument is manufactured by C. H. Stoelting Co., Chicago. The particular one employed belonged to the Massachusetts State Psychopathic Hospital, Boston, and was kindly loaned to us for the period of the experiment.

[2] See Whipple, Manual of Mental and Physical Tests, part 1, Baltimore, 1914, p. 100, for standard recommendation of procedure. The men were asked to remove any rings from their fingers during the test.

[3] Kohs, Journ. Exp. Psychol., 1917, 2, pp. 304 ff.

ing and the standard weights. The average error, particularly in that range which was commonly employed, which is from 35 to 70 kg., is usually less than ±0.2 kg. with the higher temperature, which was more nearly the condition used under actual experimentation, as the subjects desired to have the rooms in which they worked quite warm.

It was seen that no such discrepancies or errors between standard weights and dynamometer readings were found in the case of this instrument as those recorded by Kohs, and therefore our readings are given without correction. With the exception of three occasions, the readings were always made by the same individual. These times were: the evening of December 19, Squad A; morning of February 3, after the walking experiment, Squad A; and the records which were taken in Springfield on May 21 and 22.

TABLE 8.—*Calibration to check the accuracy of the hand dynamometer used in this research.*

Standard weights in kg.	25° C.		13.5° C.		Standard weights in kg.	25° C.		13.5° C.	
	Average reading of 5 trials.	Average error between standard weight and reading.	Average reading of 5 trials.	Average error between standard weight and reading.		Average reading of 5 trials.	Average error between standard weight and reading.	Average reading of 5 trials.	Average error between standard weight and reading.
5	5.00	±0.00	....	....	45	44.84	−0.16	....	....
10	9.94	−0.06	....	....	50	49.90	−0.10	49.54	−0.46
15	15.30	+0.30	....	....	55	55.14	+0.14	....	....
20	20.36	+0.36	20.12	+0.12	60	60.06	+0.06	59.34	−0.66
25	25.32	+0.32	....	....	65	....	....	....	....
30	30.20	+0.20	30.02	+0.02	70	70.32	+0.32	69.62	−0.38
35	34.94	−0.06	....	....					
40	40.20	+0.20	39.98	−0.02	Error.	....	+0.117	....	−0.23

(7) Changes in Pulse-Rate Occasioned by Short Periods of Exertion.

This was one of the morning measurements. A brief review of literature pertaining to pulse records of this sort and a description of technique previously used has been given in another publication by one of us under the convenient name of "tetanus pulse."[1] Formerly the changes in pulse-rate were produced by the subject's clenching his fists and making the muscles of arms, legs, and trunk rigid for a given period, after which he relaxed in a steamer chair as he had been previous to the exertion. From the standpoint of quick transitions from rest to exertion, and from exertion to rest, no routine can be better, but, as pointed out in the previous publication, much depends upon the subject for the amount of exertion actually put forth and in sustaining it with some uniformity during the period.

[1] Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 92.

The method in the present research and in some previous unpublished studies is clear from an inspection of figures 22 and 23. The subject, connected to the string galvanometer, reclined comfortably in a steamer chair. Above him and within easy reach was suspended a bar of suitable dimensions, which was easily capable of bearing the subject's weight. At a given signal he grasped the bar and raised himself to the position in figure 23, with his weight entirely free from other support. He remained in this position for a period of 5 seconds and then quickly settled back into the chair and into as complete relaxation as possible. The exertion produced in this way is more uniform than when the subject stiffens his muscles but remains seated. The bar is placed at such a height that, in order to keep the body free from other support, it is necessary to thrust the feet forward and hold them up. This causes muscular tension in abdomen and legs. Thus the whole body is exercised and it is rather unlikely that a subject would find it possible to learn to isolate the muscles most used and to keep the others well relaxed.

The photographic pulse tracing (electrocardiogram) was continuous for about 8 seconds of rest preceding exertion, during the period of exertion, and for 20 to 30 seconds following the exertion. Sample records are reproduced in figure 24. It should be noted that these records are made primarily to record heart rates. They are not standard electrocardiograms for three reasons: (1) The deflection of the string of the galvanometer is not standardized, for the string is made taut in order to reduce the large deflection caused by the swift and general body movements. (2) Electrical condensers are placed in series with the string and the subject; in this case 12 microfarads were used. These condensers serve to minimize deflections in the base-line, that is, to cut out or reduce all slow changes in potential, such as those occasioned by movement of the arms and trunk of the subject. This causes, of course, a reduction in the size of the *P* and *T* waves of the common electrocardiographic complex. (3) The points of leading off from the subject's body, that is, directly below the arms, while corresponding fairly well to Einthoven's lead No. 1 (*L1*), are not exactly the same as this or any other commonly used lead.

Figure 24 shows records for three subjects. In the illustration it has been necessary to cut each record in two. Thus, *A′* must be considered as belonging at the right hand end of *A*, and together they form one continuous record. The same applies to *B* and *B′* and *C* and *C′*. The three sections of a record are clearly marked: At the left is a short section covering 6 or more pulse cycles representing a period of rest before the exertion (the paper may be regarded as having moved from right to left when the record was being taken). Near the center is the section of the pulse record taken during the moments when the subject was supporting his weight on the bar. The string is seen to have been dis-

Fig. 22.—One corner of room C, the main psychological laboratory.

The figure shows the arrangement of a portion of the apparatus used in taking electrocardiograms under conditions of short periods of muscular exertion. The string galvanometer and arc lamp are at the left and not shown in the picture. The subject is connected to the galvanometer by electrode leads, *E*. A standardizing resistance arrangement *R* and a protection resistance *R'* make possible control of the string's deflections. Electrical condensers *C* in series with the subject and the galvanometer string minimize its disturbance at the moments of physical activity. The photographic camera *P* is driven by a motor on the other side of the wall at *M*. The action of the camera is very quiet, its speed is controlled at *S*, and the paper or film after exposure is deposited in the large dark box *D*. The bar *B*, upon which the subject exercises, is directly above him and within easy reach.

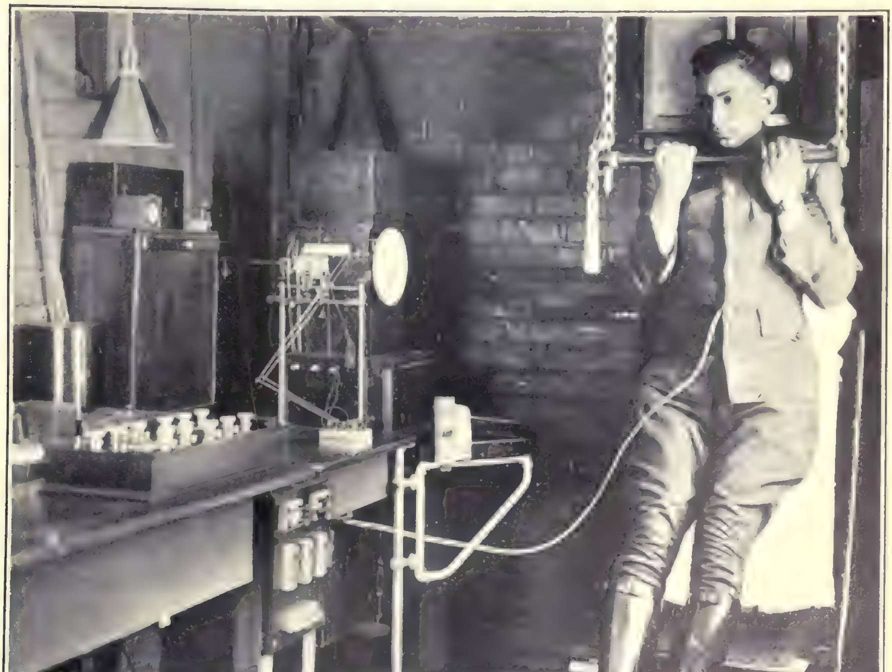

Fig. 23.—The subject in position during the moments of physical exertion.

Previous to exertion the subject reclines comfortably in a steamer chair. At a given signal he reaches, grasps the bar above him, and raises himself, thrusting his feet forward to keep all his weight free from other support, and maintains the position shown in the figure until the signal "down," at which he relaxes into the chair. The electrocardiographic record is continuous through rest, exertion, and rest. The experimenter occupies a position at the left.

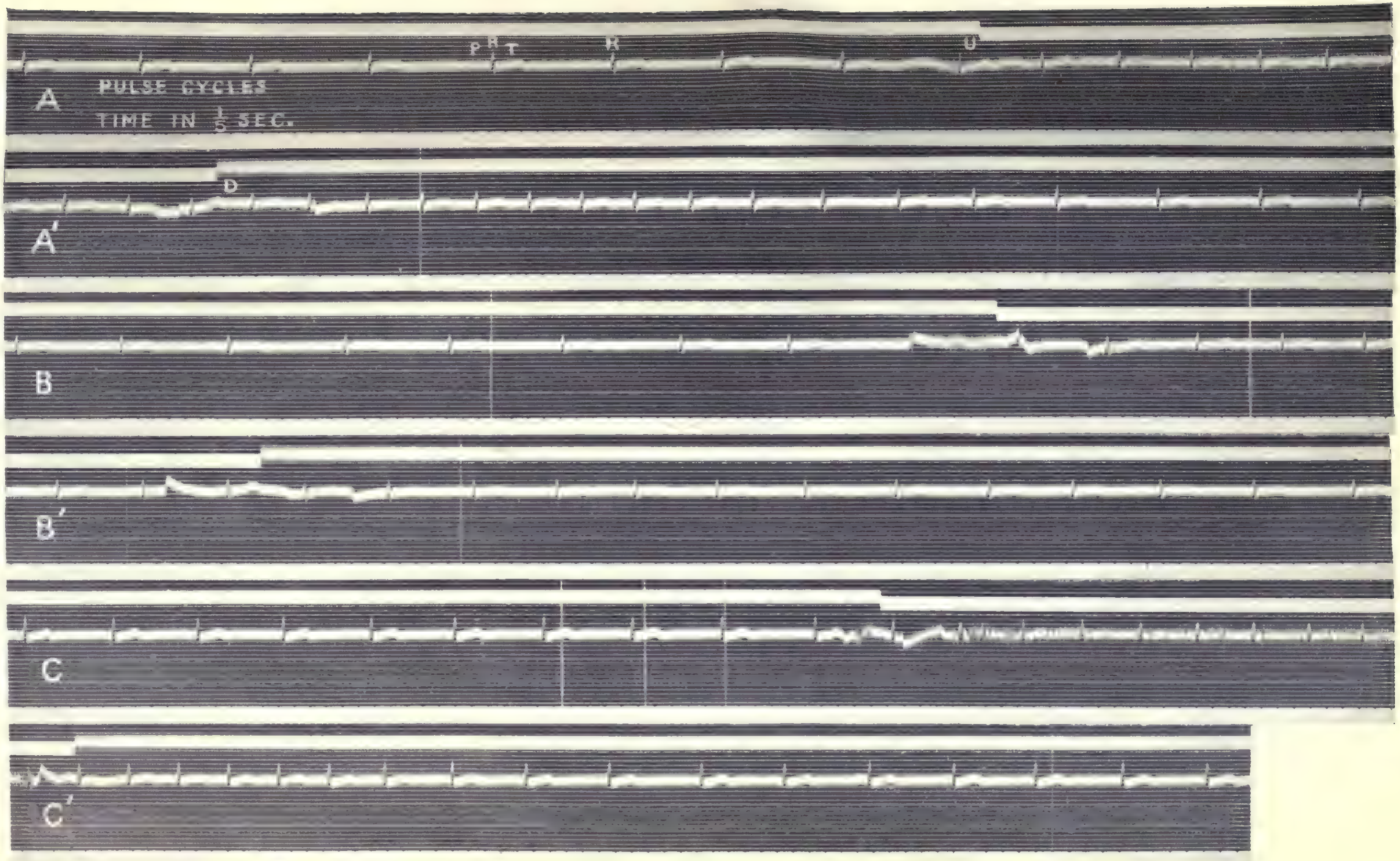

FIG. 24.—Sample pulse records showing changes in the pulse-rate occasioned by short periods of exertion.

A and *A′* are parts of the same continuous record, which has been cut for purposes of illustration. From the left-hand end of *A* to the point *U*, the subject was resting quietly in the steamer chair; at *U* (up) the weight was lifted and this muscle tension was continued to *D* (down, shown in *A′*), when the subject let himself down into the chair and was relaxed until the end of *A′*. The same description would apply to *B* and *B′* or to *C* and *C′*. The pulse-cycle length is measured from *R* to *R*, and the time is in one-fifth second. The small irregular vibrations in the pulse line show the period of activity, which obviously began before *U* and continued slightly beyond *D*. In the post-activity section of *B′*, the pulse-cycle length returns to normal rather slowly as contrasted with the changes shown in the similar section of C′.

turbed by many action currents coming from the body muscles. Suddenly these action currents cease, indicating that the subject has settled back into the chair; the pulse remains rapid or perhaps becomes more rapid than during the actual intervals of exertion, and then, gradually, the heart cycles lengthen, while the subject is quietly resting in the chair. Only the large *R* wave of the electrocardiogram complex can be seen during the period of exertion. Pulse-cycle length was measured from *R* to *R*.[1]

In order to have an added indication for placing the moment when exertion began and ended, a key was arranged at one end of the bar and was operated by the subject's weight. When this key was closed by the weight of the subject on the bar, a signal magnet which was in circuit and placed before the slit of the camera was caused to deflect. The shadow of this signal marker was recorded on the photographic paper (see *U* and *D* in figure 24.) The switch was arranged as shown in the diagram in figure 25. One of the leads, *L*, in circuit with the battery and the signal magnet, connected to the metal clamp which was about the bar *B;* the other lead connected to the brass sleeve *S*. This sleeve contained a stiff spring, one end of which rested in the bottom of the sleeve and the other against the wooden bar. The spring was around the hook *H*, which connected the bar to the chain. When the downward pressure was placed upon the bar a contact was made at point *C*. It required 4.5 kg. of weight to close the circuit. Thus the signal was given very early after the subject grasped the bar and the circuit remained closed until the subject had almost relaxed in the chair. To economize time in preliminary adjustments, the bar was kept at the same height for all the subjects during the whole experiment.

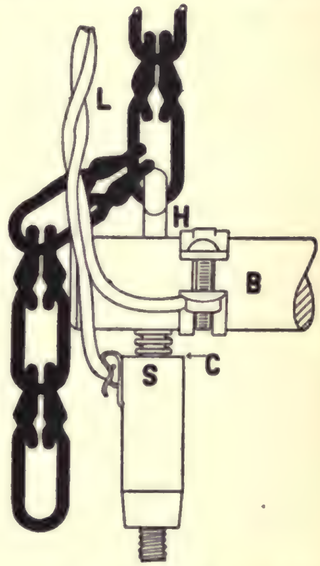

FIG. 25.—Detail of the key closed by the subject's weight during physical exertion.

H, hook connecting to chain support; *S*, a sleeve for holding a stiff spring in position against the bar, *B*; *L*, leads in circuit with battery and signal magnet; *C*, point of contact for circuit closure when weight is supported on *B*.

The form of electrodes designed and used is shown in figure 26. A set consisted of three pads, *R*, *L*, and *G*, a 4-foot cable, and a plug, *P*. Each pad was made of 8 thicknesses of cotton gauze, a piece of German silver, 0.005 inch in thickness and 11 cm. wide by 20 cm. long, with a piece of felt for backing. The edges of the gauze were tucked in around

[1] Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 95.

the edge of the metal strip and all were secured to the felt at the back. A regular 4-foot telephone cable, with wires designated, which ends in the usual switchboard plug fitting into the ordinary receptacle was employed for purposes of connection. This offers very quick connection and good contact. The gauze on the face of the pad was moistened in warm saturated sodium chloride solution. Pads *R* and *L* were placed in contact with the skin on the right and left sides of the subject; *G* was placed between them and somewhat lower on the abdomen. Two bands of elastic tape about the subject's chest held the pads in position. This tape did not have to be uncomfortably tight. Although unnecessary in these experiments, the pads could be worn a long time without annoyance, and they made good contact with the body for an indefinite time. The many thicknesses of cotton gauze provided against any scratching of the skin. *R* and *L* connected with the two terminals of the galvanometer string. *G* was connected to earth as a "ground." This method was found to be more satisfactory than to earth the frame and coils of the string galvanometer. With these electrodes it was nearly always possible to get satisfactory pulse records while the subject was engaged in the vigorous activity called for by the test.[1] These same electrodes were used in recording the pulse when the subject walked on the treadmill (see p. 129). Several sets of electrodes facilitated the experimenting.[2]

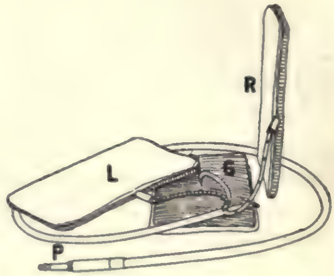

FIG. 26.—The body electrodes used in recording electrocardiograms during physical activity.

The pads were 11 cm. wide and 20 cm. long; each pad was made of 8 layers of cloth, a sheet of thin metal, and a piece of felt for backing. In use, the cloth is moistened in salt solution. *R* and *L* were applied directly to the skin on the right and left sides of the subject and connected to the string galvanometer. *G* was applied just above the navel and connected to ground; *P*, regular 3-lead telephone plug.

The electrocardiographic apparatus had been arranged in general to facilitate the taking of such records. In the nature of the case, it is most convenient to have the subject near the apparatus, but the apparatus should not be such as to annoy or distract the man. The electric motor which operated the camera was placed in an adjoining room and could run indefinitely with no disturbance. The illumination was from an automatic arc lamp. The

[1] A prominent exception to this statement is found in *Gul* of Squad A. It could never be determined with assurance whether the action currents from muscles of limbs and trunks were in his case exceedingly strong or whether this subject carried about in his body an immense static charge. However, almost every time he was tested he put the galvanometer string out of order. His case was exceptional. Nothing similar was encountered in a group of 65 young men tested previous to this research. No criticism is made of him, for he followed instructions as well as any subject could.

[2] These electrodes might not be the most satisfactory form for long periods of walking or other physical exertion, as they could shift into position of contact, one with the other, unless special arrangement was made to avoid this.

slit in front of the camera could be opened and the photographic record started by the action of a very simple lever which was not apparent to the subject. The receptacle for exposed photographic paper (*D* in figure 22, page 152), below the camera, was large enough to hold more than 100 feet of such records. The subject's chair could be easily moved to a position directly under the bar. The subject was instructed by word and illustration to take hold of the bar quickly and to bring his body up so that his chin was even with the bar, but not to support any weight by his chin. He was to lift his feet clear of the floor and to hold the position until the signal "down." When in the chair he was told to be as relaxed as possible and to act as if going to sleep. No instructions regarding breathing were given.

The experimenter commonly occupied a position which would be at the left of the picture (see fig. 22). From the large clock located on the wall back and above the subject the time interval could be accurately judged, and the signals given; the interval of exertion was usually about 6 seconds. One preliminary trial was made to insure everything being in proper relation and to relieve the subject of any excitement or embarrassment. He did not know that this was only a preliminary trial. An interval of at least 1 minute was allowed between trials. After the records had been made the subject was disconnected and the electrodes were removed. It is noteworthy that the subjects did not understand what this test involved. Several of them asked at different times, particularly at first, what it was for. The uniform answer given was: "It is a test of the involuntary nervous system." Not until January, when the same electrodes were used on the men in the treadmill experiments, did they realize that it was a test of the pulse-rate and heart action.

(8) Patellar-Reflex Latency, Amplitude, and Refractory Period.

The patellar-reflex records were made from muscle thickening. The technique was the same as that used and described by Dodge and Benedict[1] in their investigations of the effect of alcohol. The apparatus was essentially the same as that illustrated and described by these authors, but has been slightly modified since the previous description. The present form is shown in figure 31, page 160, of this monograph. It had been found that considerable latitude was needed for adjusting the height of the light wooden bar *B*, which rests against the tendon of the subject. A rough adjustment (1) and a fine adjustment (2) were arranged to raise or lower as needed the sliding base, *S*, which carried the stimulus apparatus and to which was fastened one end of the bar *B*. The position of this bar in relation to the hammers, *H*, was constant, regardless of whether the bar was raised or lowered. A screw clamp (3) made possible the suitable adjustment of the height of the other end of the bar.

[1] Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, pp. 36 ff. They illustrate their apparatus in their fig. 4.

In actual use the apparatus was not placed as in figure 31, but was moved closer to the table. The subject's left foot was placed at F, and his shin rested in the two notches above. The position of the subject under the stimulus apparatus was so oriented that A, the adjustable connection between the quadriceps muscle and the light-recording lever which rests on the kymograph drum, was directly over the middle of the quadriceps muscle. The hammers, H, fell through 90° from the magnets, M.

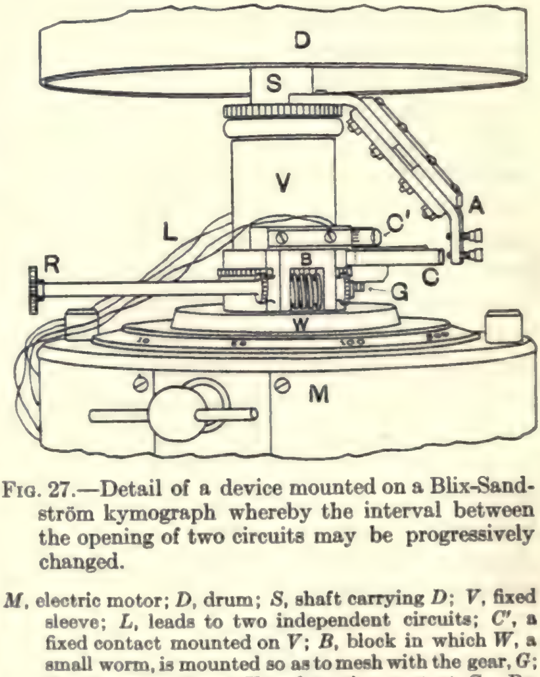

FIG. 27.—Detail of a device mounted on a Blix-Sandström kymograph whereby the interval between the opening of two circuits may be progressively changed.

M, electric motor; D, drum; S, shaft carrying D; V, fixed sleeve; L, leads to two independent circuits; C', a fixed contact mounted on V; B, block in which W, a small worm, is mounted so as to mesh with the gear, G; G is movable about V and carries contact C. By turning the hand wheel R, which actuates the worm and gear, C may be made to advance or recede from C' which is fixed. The insulated arm, A, carried by S and revolving with D, opens C and C' in turn, regardless of their relative positions.

A modification was made on the Blix-Sandström kymograph whereby the interval between the two blows from the hammers could be gradually lengthened or shortened at will without causing an interruption in the experiment. The general form of this modification is indicated in figure 27, where M is the kymograph motor and shift gear and D is the drum. A movable gear, G, in the form of a collar, is mounted on the fixed sleeve, V, through which the moving kymograph shaft S extends. To this movable gear a block of insulation material is secured which carries a contact or switch device, C. A small brass worm, W, mounted in the fixed block B, engages with the gear. Thus, by turning the rod R, which extends to a convenient position for the operator, the contact C may be moved in relation to the fixed contact C'. Each contact is made of two leaves, one longer than the other, which, by their spring tension, hold themselves together. The insulated arm A is mounted on the revolving shaft and turns with the kymograph drum. The adjustable points in the end of this arm sweep past the contacts and open them in turn, whatever may be their relative positions. As these switches are in series with the electro-magnets (see M, fig. 31) which are supporting the hammers just previous to the stimulation of the patellar reflex, they control the action and the interval between the blows. The wiring diagram

for the apparatus as used is shown in schematic form in figure 28. The meaning for the different letters is given in the legend of this figure.

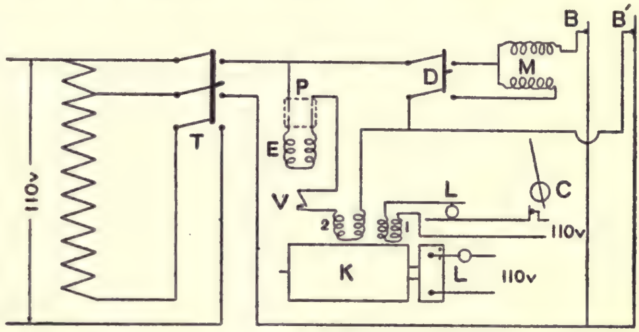

FIG. 28.—Schematic wiring diagram for the apparatus used in room B in the evening measurements: patellar reflex and word reactions.

A triple pole switch *T* and a double pole switch *D*, when closed, caused current to flow in the electro-magnets *M*, which held up the pendulum hammers used to stimulate the patellar tendon for eliciting the reflex. The hammers were released from the magnets when the circuits were broken at *B* and *B′*. The temporal relation of these could be changed (see fig. 27). A large clock *C* interrupted a circuit (110 volts, lamp *L*, in series, 0.5 amp. current flowing) and so actuated an electro-magnet, 1, and registered the control time on the kymograph *K*. By opening *D* and connecting the exposure apparatus *E* in circuit by means of the plug *P*, the word reactions could be recorded. The opening of the circuit at *B′* exposed the word and caused at that instant the operation of the marker, 2. The circuit was reestablished at *B′* before the subject could react by speaking into the voice key *V*. The reaction opened *V* and the marker, 2, was operated a second time and recorded the moment of response.

The subject reclined in a steamer chair, the height of which was the same for all subjects and all sessions. At first the patellar tendon was explored to find the point of greatest sensitivity. Then, beginning with the stimulus blows separated by an interval of 0.8 second or thereabouts, the interval was gradually shortened until the second stimulus failed to produce a reflex. Then the interval was varied in length a number of times in an effort to secure several records in which the second stimulus produced only a slight reflex or no reflex at all. The 100-gram weights did not seem to be uncomfortably intense for any subject. Some of the subjects had no reflex which was measurable. The routine was carried out, however, in every instance, so that if a reflex should suddenly appear or become sensitive it would not be omitted. This did happen to some extent in the case of *Tom*, Squad A, who, after an operation for hemorrhoids,[1] had a reflex which was considerably larger than that he had previously shown in the experiment. A sample record, reduced in size, is given in figure 29. The records for patellar reflex, finger movements, and word reactions taken on the subject in room B were all made on the same kymograph paper. The reader will therefore disregard for the present the part of the record below the cross which may be seen on the left side of figure 29. The reflex record (see upper part of fig. 29) was started near the middle of the paper, where the interval between reflexes is longest. Reading a record from

[1] See his personal history, p. 52.

the left, the fall (*1*) in the line is caused by the stimulation of the tendon; the second drop (*2*) is from the reflex thickening of the muscle. The distance from the beginning of *1* to the beginning of *2* is the latency for the reflex, which is measured in thousandths of a second (the kymograph speed was 100 mm. per second). The amplitude is the vertical

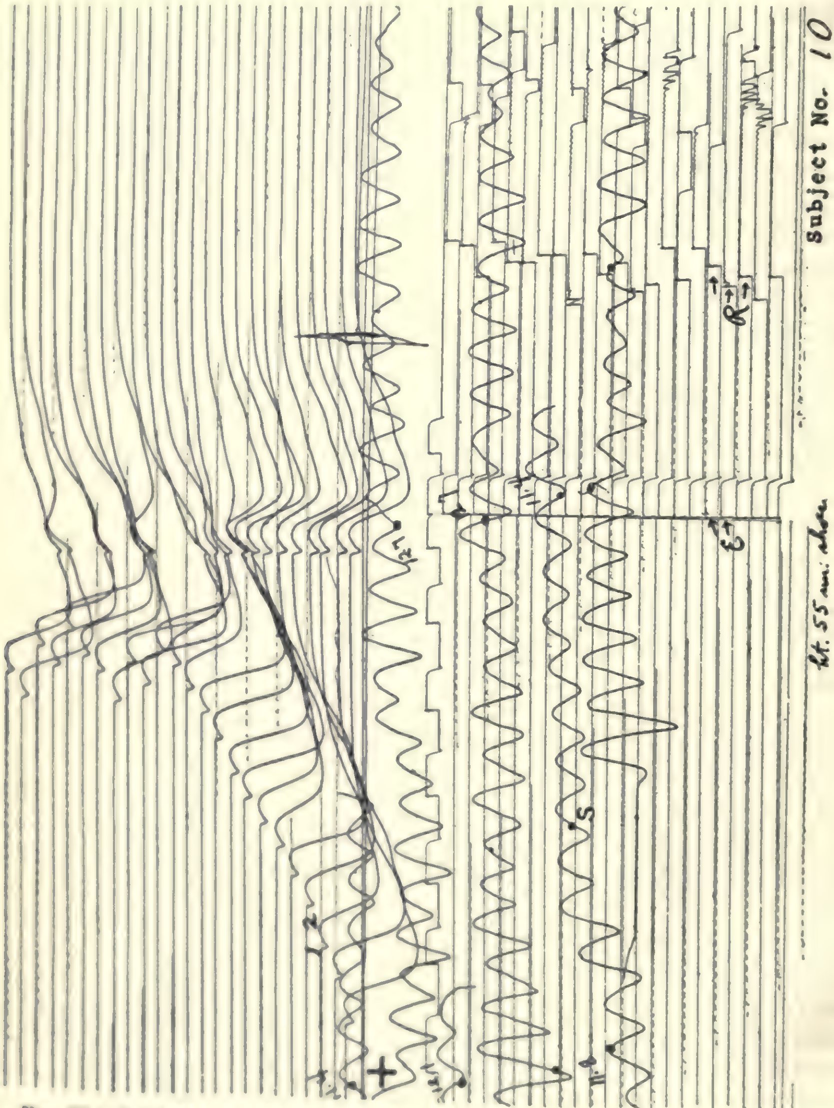

FIG. 29.—A portion of a sample record for the evening measurements in room B. The curves above the cross, which is in the left of the figure, are from the patellar reflex and show a gradual shortening of the interval between stimuli until the reflex for the second stimulus is absent. The wavy and more or less irregular lines in the lower portion of the figure are from the finger movements. The black dots were caused by the jump sparks and indicate the 2-second intervals. The horizontal broken lines in the lower section are the word-reaction records.

distance from the base-line of *1* to the lowest point of *2*. The mechanical magnification in the record was 6 times the actual height of muscle-thickening.[1] There is naturally some confusion in the tracings of such records, but it is evident that when the interval between stimuli is decreased to a certain point, the second stimulus fails to produce a reflex. When the interval is lengthened slightly, a small reflex appears in response to the second stimulus. A record was kept of the height to which the bar which rests against the subject's knee had to be raised, and also whether the subject had on shoes or slippers.

(9) Reaction Time for Turning the Eye to a New Point of Regard.

This measurement was always made in the morning. The turning of the eye to a new point of regard in response to the sudden appearance or movement of some object which is removed from the line of clearest vision is an important reaction for the organism. It would seem that, considering the multitude of reactions of this character which an individual makes in the course of his everyday life, an adult subject in coming to the Laboratory would be perfectly practiced in this regard. In any wide range of neuro-muscular measurements, particularly when new and unpracticed subjects are to be used, this measurement of eye reactions is an especially promising one for consideration and use. Suitable apparatus for photographically recording the eye reactions has been designed and used by Dodge and has been fully described by him.[2] Briefly, the record is made by photographing a beam of light reflected from the cornea of the subject's eye. This calls for a source of illumination, an adjustable head-rest, mirrors, a lens, a camera of suitable design to move the photographic plate, and some device for presenting stimuli to the eye.

Several modifications and additions have been made to the apparatus as used by Dodge and Benedict in the alcohol investigation. Certain definite aims were in mind in making these changes: (1) a form of stimulus device was desirable, which would provide more variety of stimulus positions and still give no secondary criteria to the subject; (2) the field of view of the subject should include only what was necessary for him to see; (3) it should be possible to place a new subject in position quickly and to inform him definitely of his task; the subject who is familiar with the test should be able to place himself in position, adjusting the head-rest as directed by the operator; (4) for laboratory economy, as well as to avoid the possibility of giving secondary criteria to the subject, the apparatus should be operated by one person, and from one position; (5) more reactions should be taken to get a better sample of the sub-

[1] The records for some readers might be more easily understood in connection with the actual movements of the muscle if the figure is turned upside down; a rise in the curve will then be seen to correspond to a rise or a thickening of the muscle.

[2] Dodge, An experimenta study of visual fixation, Monograph Supplement of the Psychological Review, No. 35, 1907. See also Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 79.

ject's performance. These points were met, as described in the following paragraphs.

As Dodge has pointed out, there is no limit to the number of reactions that can be recorded on the same photographic plate, except that beyond a certain number they will become confused with each other and, on that account, illegible. It appeared to us that reactions, photographed on the plate at intervals of one-eighth inch, would be sufficiently legible, provided the subject kept his head quiet in the head-rest. Accordingly a device was arranged to move the Dodge falling-plate camera laterally by small increments. See *V*, *W*, and *T* in figure 30, also *V* in figure 41. A treadle *T*, shown in the lower left-hand corner of figure 30 and worked by the operator's left foot, was kept in position by a spring and connected to a pawl, which, when drawn down, engaged with a toothed wheel at *V*. From the shaft on which the toothed wheel was mounted a light cord connected with the body of the camera. When the wheel was turned to the left, therefore, the camera was drawn to the left; the weight *W* kept the string taut and made the movements to the left fairly easy. The camera was supported on two slides which moved easily on the surface of the table. Usually the camera was moved over one step for each reaction, unless it was necessary to focus between reactions, when it was often moved two steps. By this method of moving the camera it is not necessary to focus so frequently as when the camera is moved by hand, which is usually a rougher judgment. The device made it practical to take 15 or 16 reactions on one plate 2½ by 7 inches in size. The camera could be moved freely right and left when the operator's foot was not on the treadle, *T*.

In beginning to take records on a plate the camera was moved to the right, and the beam of light from the subject's eye focused on the glass *G*, below the plate *P*, and at a position indicated by the small cross. (In the Dodge camera the arrangement which holds the plate-holder containing the photographic plate, *P*, moves downward with the flow of

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EXPLANATION OF FIGURE 30.

F, focusing hood of camera; *G*, ground glass focusing screen; *B*, by-pass oil cylinders; *P*, photographic plate in frame which moves downward with the flow of oil; *S*, shutter to expose *P*, opened by cord, 1, when *P* is completely raised and closed by cord, 2, at the completion of the fall of the plate; *C*, sliding contact operated by the movements of the plate-holder; *D*, drip-pan for oil; *T*, foot treadle operating a pawl on a toothed wheel at *V* by which the whole camera is moved short distances to the left for successive eye reactions; *W*, weight to keep taut the cord connecting the camera to *V*; *X*, strings by which the experimenter may operate the exposure apparatus not shown in this figure.

EXPLANATION OF FIGURE 31.

All three measurements employed the Blix-Sandström kymograph. See fig. 28 for wiring diagram. *F*, position of foot when recording patellar reflexes; *B*, light wooden bar, the right end of which rests against patellar tendon; *H*, pendulum hammers which, when released by the electromagnets, *M*, fall against *B* and produce stimulus for reflexes; *S*, movable base carrying the frame for *M* and *H* adjustable to height for different subjects by 1, 2, and 3; *A*, adjustable connection between quadriceps muscle and recording lever. *E*, exposure apparatus for word reactions in position clamped to post, *P*; *W*, window in which the words appear; *V*, voice key for reaction of subject.

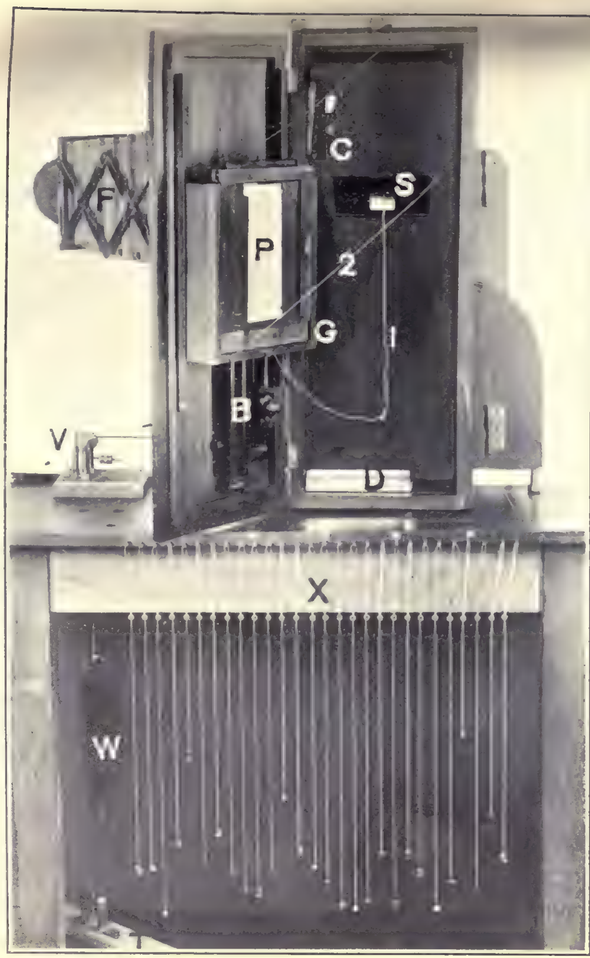

Fig. 30.—Details of the falling plate camera and accessories used in recording eye reactions. The experimenter's end of the apparatus.

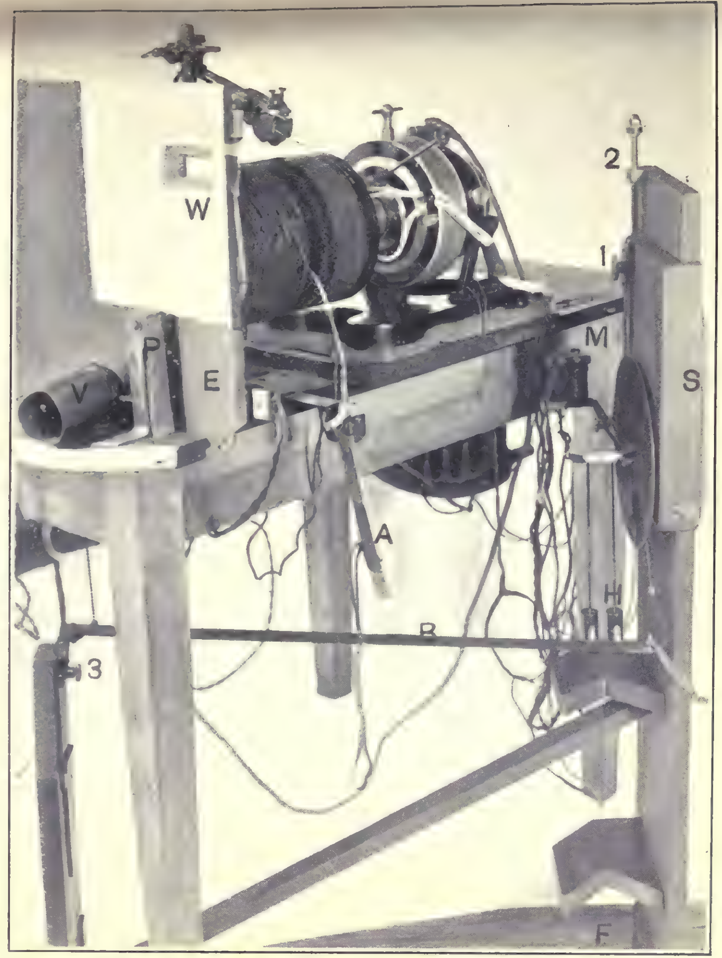

Fig. 31—The apparatus used in room B for patellar reflex, word reactions, and finger movements.

oil through the by-pass cylinders, *B*.[1]) The up and down movements of the plate-holder were made to open and close a shutter, *S*, by means of the cords *1* and *2*. When the plate-holder was drawn up by hand, just before it reached its highest position, and when the ground glass, *G*, came opposite the shutter *S*, string *1* became taut and opened the shutter. This remained open until the fall of the plate was complete. String *2* then became taut and closed the shutter. Thus the plate was protected from fogging, except during the actual moments when reactions were being recorded or the camera was being focused.

A sliding contact was arranged at *C* (figure 30) in the camera. This completed a circuit for the small solenoid *S* (see figures 34 and 35). This by its action caused the light to be turned on the eye of the subject at the same instant that the stimulus should appear. After the plate had completed half its fall the current was cut off from the solenoid by the breaking of the contact. This contact, *C*, was composed of two slots in a hard-rubber block, the slots running slightly diagonal to the perpendicular movement of the plate. A small wire brush placed at the upper right-hand corner of the plate-holder moved in these slots. When the plate was at the top this brush was in such a position that it slid down the left-hand slot, which was lined with copper. It thus completed the circuit and actuated the solenoid mentioned. In its downward course the brush was gradually drawn to the left. When the plate had passed half its fall and the brush left its path, it swung back in such a position that when the plate-holder was raised it traveled up the path at the right, which, being composed of hard rubber, did not complete the circuit through the solenoid. In this way the stimulus and exposure of the eye did not have to be separately operated, but were automatically timed in relation to the fall of the plate.

The strings which hang from the end of the table (see *X* in figure 30) connect with the stimulus device. As the operator sits at this end of the table behind the camera they are in easy position for him to use.[2] The easily controlled and silent action of the stimulus apparatus, the accurate means for shifting the position of the camera, the automatic action of the shutter to avoid the fogging of the plate, and the automatic timing of the stimulus in relation to the fall of the plate, all contributed to make possible the taking of reactions with a minimum loss of time. If it is not the first time the subject has served in the experiment, 6 to 8 minutes is ample for the taking of two plates, that is, a total of 25 to 35 reactions. These modifications also help to make possible the control of the apparatus from one position and by one person.

The adjustable head-rest which made possible the placing of the subject in position quickly, and later his placing himself in position, is

[1] See description in Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 80.

[2] In figure 50, p. 185, the schematic ground plan of the apparatus for eye reactions and eye movements at the subject's end is shown. *C* in this figure represents the stimulus apparatus and the cords to operate the same which extend to the other end of the table, hanging there in convenient position for the experimenter.

shown schematically in figure 32. The forehead of the subject was placed against the curved wooden support, *S*. A wooden peg, *T*, was taken between the teeth. The blind, *B*, was down in front of the eye or raised up out of position. In the test for the eye reaction it was always raised out of view, as the subject looked at the stimulus with both eyes. The lens of the camera was at position *A* in the figure. The support *S* may be raised and lowered as indicated, but usually it was not necessary to make any change here. The adjustment was commonly with the two rack-and-pinion devices, operated by knurled heads, *K*, and with the movable tooth-rest. The clamp *W* was first released by turning the wing-nut; then the whole frame of the head-rest was shifted laterally or vertically as the case required. When the position was found, the clamp *W* was tightened; the support for the head was then rigid. The whole frame could be moved far enough to the right so as to use the left eye for photographing if desired. The changing of the wooden pegs and the cleaning of the nickel-plated support are easily done. The right-hand bearing of the lower rack-and-pinion device is fitted with a clamp so that the head-rest will not have a tendency to drop down without the observer's knowledge.

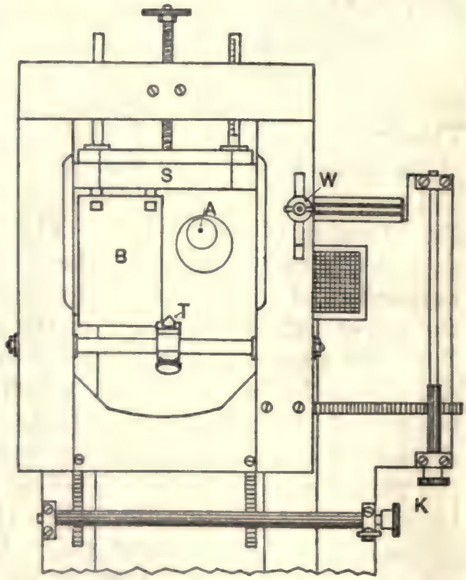

FIG. 32.—Diagram of the adjustable head-rest.

S, forehead support; *T*, tooth rest; *B*, opaque blind for left eye; *K*, knurled heads controlling the rack and pinion devices; *W*, wing nut clamp for fixing the head-rest in any desired position; *A*, position of lens or artificial pupil.

The general arrangement of the apparatus from the subject's end may be seen in figure 35. The head-rest is shown in profile. A white line has been drawn in the picture to show the general course of the beam of light which is used to photograph the movements of the eye. The beam is of soft blue light, and when the subject is following instructions can only be seen in indirect vision. As used in the experiment it is not tiresome to the eye, but has sufficient actinic power for the photographic recording. In actual operation a small shield (see the black perpendicular line to the right of *A* in figure 35) obstructs the path of the photographing light so that it does not fall on the subject's eye until the exact moment when the stimulus light appears. The stimulus light appears in a position to the left of the subject's field of view, in the location indicated by *L* in figure 35. The area over which these stim-

ulus lights may appear is about 25 cm. square. This area forms one side of the lamp-house, *H*, which contains four 60-watt Mazda lamps. The lamps were arranged upon a cluster plug; the inside of the house was white, ground glass being used to diffuse the light. There were 28 stimulus units arranged in the door of the box which faces the subject. A section of this part of the stimulus apparatus is shown diagrammatically in figure 33 from within the box. *W* is a three-ply wooden door. On the outside of this, that is, near the subject, is a milk glass, *G*, and over this a metal plate, painted flat black and containing holes 2 mm. in diameter, through which the light may pass to the subject's eyes. Twenty-eight small shutter devices, like that shown at *S* in figure 33, were arranged. When opened by the cords *C* (which extended to the operator's end of the table, see fig. 30) they each exposed a round hole in the door, 1 cm. in diameter. In this way the light was allowed to fall on the milk glass and a certain portion of it went through the opening in the plate to the subject's eye. The shutters were all fitted with black velvet, thus making them light-tight when not operated. The four 60-watt Mazda lamps were in parallel, as shown at *L* in figure 34, and constantly in series with the resistance *R*. Thus, when contact was made at the mercury switch, *M* (figs. 34 and 35) the resistance *R* was swiftly short-circuited and the lamp filaments came to full brilliancy in a very brief interval.[1]

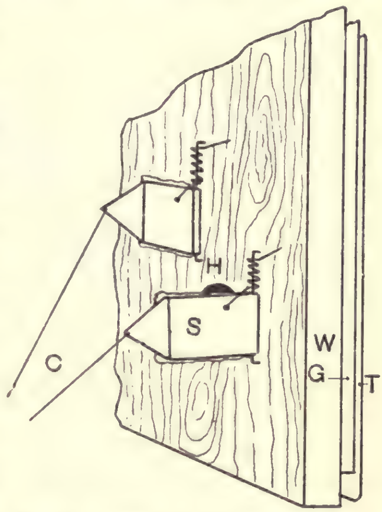

FIG. 33.—Detail of the small shutters and windows in the eye-reaction stimulus apparatus.

S, shutter controlled by cord, *C*, for opening the 1 cm. holes, *H*, in the wooden door *W*; the light thus came to the milk glass, *G*, and a portion of it passed through the 2 mm. opening in the thin metal sheet, *T*, the exposed surface of which was painted flat black.

The circuit of the solenoid, *S* (figures 34 and 35) was completed by the sliding contact *C* (figures 30 and 34), as explained in connection with the modifications made in the falling-plate camera. From figure 35 it may be noted that when the solenoid acted, the part designated as *1* was shifted to the left in the picture. This caused the falling of the frame *2* resting on the top of *1*. This frame carried the shield *A*, which interrupted the beam of light until that moment when the falling of this frame turned the photographic

[1]In this report our interest is in comparative results. It may, however, be stated that 0.02 second for latency of apparatus should be deducted from the values as printed to reduce them to an absolute basis. This factor was determined from photographic records taken specifically to reveal the constants of the apparatus.

light on the eye of the subject and at the same instant completed the circuit in the mercury switch, *M*.

The sequence of events just preparatory to recording an eye reaction was therefore as follows:

(1) The operator grasped some one of the cords leading to the stimulus device and, by gently pulling, opened a window and held it open. The lamp filaments were glowing red in the box behind the milk glass, but did not give off enough light to make it possible for any subject to discover which window was open.

(2) The photographic plate was released. Very early in its fall it completed the circuit for the solenoid. The action of this quick and powerful magnet released the frame designated *2* in figure 35.

(3) The sudden downward movement of the frame and its parts caused the exposure of the eye to the soft blue photographic light, and at the same instant the completion of the short circuit which brought the stimulus light to full brilliancy in the opened window.

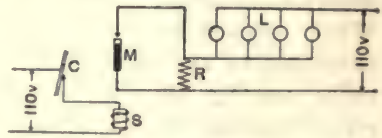

FIG. 34.—Wiring diagram for the eye-reaction stimulus apparatus.

L, four 60-watt Mazda lamps in parallel; *R*, resistance always in circuit; *M*, mercury switch for short-circuiting *R*; *C*, sliding contact; *S*, solenoid for operating *M*.

Two other cords shown as *C* in figure 35 were useful in manipulating the apparatus. One was connected with the shield which temporarily interrupted the beam of light from the subject's eye. This could be drawn down for a moment when focusing and finding position. The other was so arranged that, by pulling on it, the frame *2* could be raised into position after a reaction had been taken and thus made ready for another reaction. This lifting of *2* cut off the light from the subject's eye and broke the circuit to the lamps in the house, *H*. In the photograph made for figure 35, three of the shutters have been opened so as to expose the light, which can be seen at the points near *L* in the figure. In the center of the field at which the subject looked there was a white fixation mark which always re-

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EXPLANATION OF FIGURE 35.

B, black screen surrounding subject's field of view; *H*, lamp house of stimulus apparatus; *L*, general location of stimulus lights; *F*, a screen carrying a fixation mark and to be folded down over the plane *L* when eye movements are photographed; arrows indicate the path of beam of light; *S*, a solenoid which, when operated, moves support, *1*, to left, causing frame, *2*, to fall; *2* carries the shield, *A*, and a part of the mercury switch, *M*; thus, its fall lights the lamps in *H*, producing a stimulus at *L*, and exposes the eye to the recording light; *C*, two cords, one for lifting *2* again into position, the second for withdrawing *A* while the camera is focused.

EXPLANATION OF FIGURE 36.

Each line of dots is a reaction record. A black dash with one interspace represents 0.01 sec. Counting from the bottom (stimulus) the first definite bend in a line of dots indicates the moment of reaction, *e. g.*, in the extreme left hand record 20 dashes are counted between these points, the reaction time was therefore 0.20 sec. The records are from two subjects; those in the left hand plate show shorter and more regular reactions.

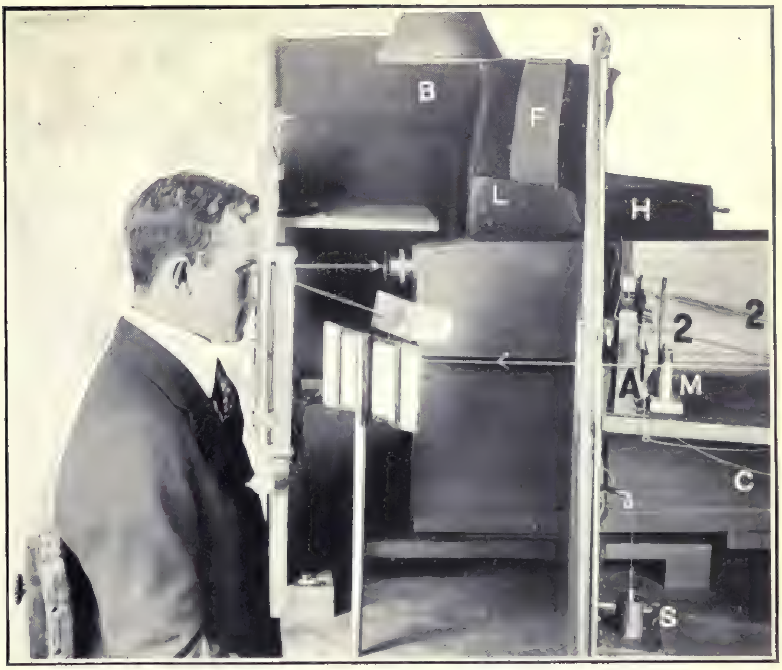

Fig. 35.—A subject in position at the photographic apparatus and ready for the eye reactions.

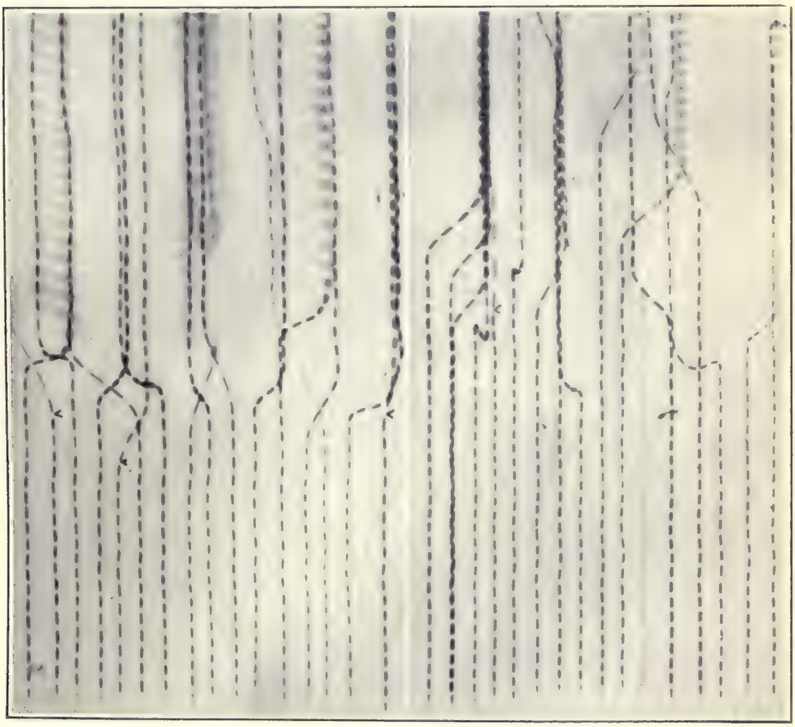

Fig. 36.—Sample eye-reaction records, unretouched, reproduced full size from contact prints of the original plates.

mained unchanged.[1] The stimulus openings were arranged on four axes passing through this fixation mark, that is, horizontal, vertical, and at angles of 45°. The points were 2 mm. in diameter and on any axis were arranged 3, 6, and 12 cm. from the central fixation mark. In the four corners of the viewed field there were points which were 15 cm. from the fixation mark. The field was 45 cm. from the subject's eye.

The stimulus device was perfectly satisfactory for our purpose, save that occasionally some one of the shutters would fail to close completely. In the measurements taken in this research and in many others made previously no secondary criteria can be discovered as coming from the stimulus apparatus. A slight sound due to friction can be heard when a string is pulled to open a shutter previous to giving the stimulus for reaction, but this sound is localized, as being behind the lamp house and under the table. In this investigation the inner ring of stimulus positions, that is, those which were only 3 cm. from the fixation point, were not used, nor were the positions vertically above and vertically below the fixation position. This limited the number of stimulus positions to 16, all of which were used with about equal frequency with any one subject.

Sample records of the eye reaction are reproduced full size in figure 36. The light which falls upon the subject's eye is interrupted by a timing vibrator and so causes the photographic record to appear as a row of short dashes. Each dash with one interspace is equal to 0.01 second. The records are to be read from the bottom upwards. When the line of dashes suddenly turns right or left it indicates that the eye of the subject has moved in the direction of the stimulus light. The number of dashes from the beginning of the record to the point where movement begins gives the reaction time. The records illustrated are from two subjects. Those shown in the right-hand plate are seen to be, in general, longer and more irregular than the others.

(10) Reaction Time for Speaking 4-letter Words.

The apparatus for the word-reaction measurement comprised a kymograph with a circuit breaker (fig. 27, *C*, the movable contact), a Deprez signal magnet, an exposure apparatus, and voice key. The general arrangement of the apparatus is illustrated in figure 31. The Deprez signal marker is seen above and in contact with the kymograph.[2]

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[1] In the stimulus apparatus previously used, the fixation mark disappears at the instant when the true stimulus comes into view. This gives the eye the impression that the fixation mark has shifted position rather than that something new has appeared.

[2] Another signal magnet not distinguishable from the Deprez marker in figure 31 is used for control time on the kymograph. This marker comes in contact with the kymograph for a very short period every 2 seconds. This method of controlling the time was used by Dodge and has the unique advantage that while the time is on the record it is not conspicuous and does not complicate the other curves. See figure 28, page 157, for the wiring diagram, and figure 29, page 158, for sample record showing control time.

The exposure apparatus *E* (see figure 31, page 160) when used is slipped into position at the end of the kymograph and clamped to the post *P*. The stimulus words were visible to the subject through the window *W*. The voice-key *V* is connected with flexible cables and may be used in any convenient position. The voice-key is the one used by Dodge and Benedict, and described and figured by them in their publication.[1] The exposure apparatus was also the same as that described by Dodge and Benedict in their figure 30, which shows the construction of the back of the apparatus not visible to the subject.

One modification which greatly facilitated the taking of reactions with this exposure apparatus was in the clip which holds the card in position for exposure at the end of the movable arm. A holder was substituted which would contain a pack of 25 cards, each card having a stimulus word printed on it. Thus, following a reaction, it was only necessary to lift the arm of the exposure apparatus and withdraw the card bearing the word which had just been reacted to; the apparatus was then ready for the next reaction when the movement of the kymograph shaft broke the circuit and caused the second stimulus word to come into view in the window. Previously, when it was necessary to put in a card before each reaction, as well as withdraw the one which had just been reacted to, it was not possible to take reactions faster than one in every 10 seconds. This made the measurement somewhat tedious, or at least it appeared so with certain subjects.[2] With the pack arrangement of the stimulus cards it was easily possible to take reactions every 5 seconds, and had there been a convenient kymograph speed the time could have been still shorter without inconveniencing the subject or the experimenter.[3]

The position of the exposure device, with reference to the subject and to the other items of apparatus, is shown in figure 31. The subject sat in a position which would be at the extreme left in this figure. The voice-key *V* was held in the right hand and the arm was supported on a convenient rest not shown in the picture. Thus the moving kymograph drum and other distracting features of the apparatus were hidden from the view of the subject, as the exposure apparatus occupied the greater part of his field of view. The area about the window, where the stimulus words appeared, was a light gray.[4]

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[1] Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 99, fig. 16. Photographic records for the latency of the voice-key as connected with different signal markers, and for the pronunciation of different words are given by them in their figs. 17 to 20.

[2] Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 66.

[3] Reference should be made to fig. 28, p. 157, for the wiring diagram for the word-reaction apparatus.

[4] In the previous use of this apparatus (Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915; Miles, Carnegie Inst. Wash. Pub. No. 266, 1918) the exposure device was placed at the other end of the kymograph. (See Dodge and Benedict, p. 95, the lower right-hand corner of fig. 14.) The subject occupied the same position as in the present research, and thus had the moving kymograph in his field of view when he was reacting to the words presented by the exposure apparatus.

Word reactions are illustrated in figure 29 (p. 158) in the portion of the record below the cross. Beginning at the bottom of the record and reading from the left, the first break in the line, designated as *E*, signifies the exposure of the word. The next *upward* movement of any one specific line is the reaction. The peripheral velocity of the drum was 100 mm. per second. The reactions are very quickly read by placing a ruled glass plate over the record, and since the exposure positions formed a straight line as in the record illustrated, it is not necessary to move the plate to read each reaction in turn. In computing results adjustment was made for any inaccuracy in the speed of the kymograph. When the reactions were finished the experimenter took the voice-key in his hand and shook it gently. This produced a series of breaks in the line which is nearest the cross in figure 29, and served as a rough standardization for the action of the key.

Suitable illumination was provided at the back of the subject and directed over his right shoulder at the exposure apparatus at such an angle that reflected light was not troublesome to the eyes. The apparatus, as used, was very convenient to both subject and experimenter. The 25 reactions, including preliminary adjustments, require approximately 3 to 3½ minutes. The subject was instructed to speak quickly and distinctly "each word that came into view." The words were all 4-letter, 1-syllable English words. Those employed were to some extent the same as had been previously used in other word-reaction and memory experiments. A subject was shown all the words to begin with before the first reaction measurements were taken. The same words were always used, but particular care was taken to keep the cards clean and the pack of cards was well shuffled before each trial. Thus, while the subject became thoroughly familiar with the words, he had no way of anticipating their order of exposure.

(11) Continuous Discrimination and Reaction in Finding Serial Numbers.[1]

On a sheet 8 inches by 10 inches the numbers 1 to 50 are arranged in an irregular order, as indicated in figure 37. The task assigned the subject was to point to these numbers in order, beginning with 1 and continuing, without skipping any number, until he reached 50. The complexity of the pattern which must be followed in touching each one of the numbers successively and in the right order is shown in figure 38, starting with *S* and ending with *E*. The test blank was on a table in

[1] This convenient test was brought to our attention by Dr. Francis N. Maxfield, formerly of the Psychological Laboratory and Clinic, University of Pennsylvania. In a personal communication he states that it was arranged by Mr. Charles K. Taylor, while working with Professor E. L. Thorndike at Columbia University, and suggests that it might be called "The Taylor Numbers." Mr. Taylor, now in the Government service, has used the test with subjects of different age groups. His subjects were required to connect the numbers by drawing lines (see our fig. 38), starting at 1 and continuing as far as possible during the 2-minute period allowed. He informs us through Captain Smiley Blanton that subjects about 20 years old could find and connect the first 22 numbers within 2 minutes. He was unable to supply any reference to a printed article describing the test.

front of the subject at the usual reading distance. He used a long pencil with a rubber eraser on the end and touched the numbers in turn with the rubber end, but did not speak them aloud. An assistant took the total time with a stop-watch and observed the entire performance to make sure no numbers were skipped.

In order to repeat the experiment with the same subject at different sessions, five different test blanks were prepared. The numbers placed on the sheets were half-inch, black, gummed figures. When the first sheet had been prepared with the numbers in position, as illustrated in figure 37, the next sheet was made by advancing each number one position on the sheet. Thus, on the second sheet, 2 was put in the position occupied by 1 on the first sheet, and thus throughout, until finally 1 was placed in the position occupied by 50 on the first sheet. On the third sheet the numbers were advanced one position from that given them on the second sheet, and so on for all of the blanks. Thus, the movements required in pointing to all of the numbers successively on a blank was, except for the start and finish, identical for all blanks, and could be assumed to be equally difficult. Neither the subject nor the assistant who took the time knew how the blanks were made up. No one blank was used in successive experiments on the same group of subjects. A more analytical result than the total time would have been desirable, but could not be conveniently arranged under the experimental circumstances and the time available. Naturally the single digits 1 to 9 could be most easily located. This served the useful purpose of giving the individual a satisfactory start. The test required from 1 to 4 minutes.[1]

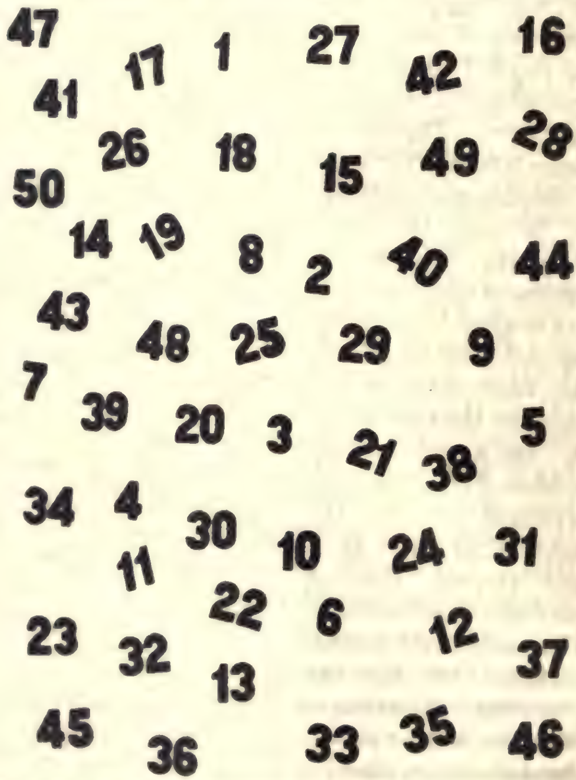

FIG. 37.—"The Taylor Numbers." The numbers 1 to 50 arranged in an irregular order as in one of the test sheets.

[1] To one watching from the side or over the shoulder of the subject the whole group of numbers occupies a position much nearer the center of the visual field. The individual numbers are more easily located. It is particularly important that the operator should in no way indicate amusement when the subject seems unable to locate some certain number.

(12) Sensory Threshold for Visual Efficiency.

The general arrangement of the apparatus for the measurement of visual "acuity" is indicated by the schematic diagram in figure 39. The subject occupied a position at the left end of the apparatus while the operator was at the right, where he could manipulate the test object and record the readings, but be entirely hidden from the view of the subject. When the subject is in position against the head-rest R the artificial pupil P is in convenient position for the right eye. The line of vision is from P through a diaphragm opening, D, through the hood H, with its several screens S which reduce to a negligible quantity the reflected light from the four sides of the hood, to the test object O. In a suitable inclosure LH a lamp is arranged so that the light is reflected at X and thrown through the test-object window. The test object is manipulated by the micrometer adjustment M. The head-rest was the same as that used in connection with the eye-reaction test (see fig. 32, p. 162). A in figure 32 represents the artificial pupil and its mounting, shown as P in figure 39. The dark blind B in figure 32 was in front of the subject's left eye. The lens of the camera, which usually is directly in front of the right eye (see fig. 35) was withdrawn and in its place a telescoping tube 5 cm. in diameter and 28 cm. in length was put in position. The end of the tube near the subject carried a small projection which was suitable for adapting the apparatus to the contour of the subject's face. At the end of this projection the artificial pupil was located. The whole telescoping tube (T in fig. 39) could be moved easily, so

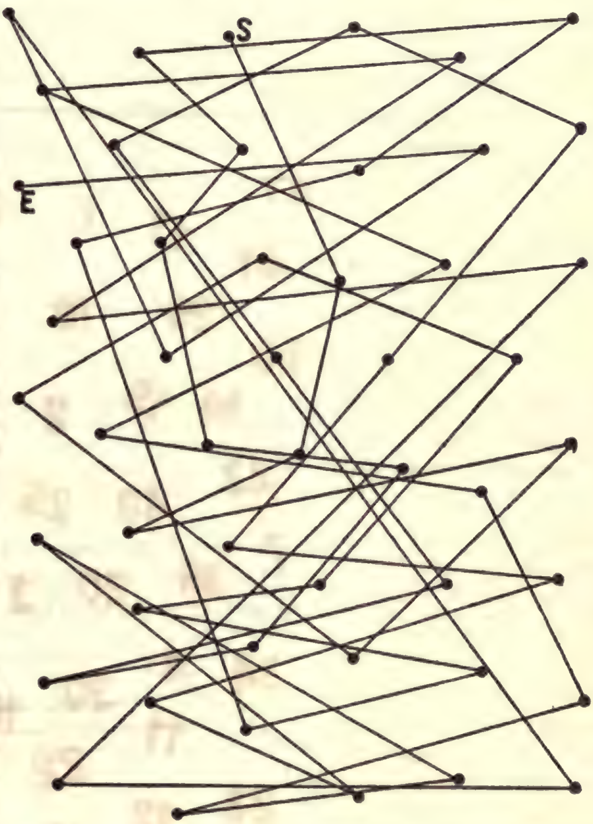

Fig. 38.—The movement pattern which should be followed by the hand in pointing out the numbers in order.

S, start of test; E, end.

that the artificial pupil was as close as convenient to the eye of the subject. The distance was usually not more than 1 cm. At the other end of the tube there was a diaphragm (see *D* in fig. 39). The round opening in this was 12 mm. in diameter. Its use and importance will become clear in later paragraphs.

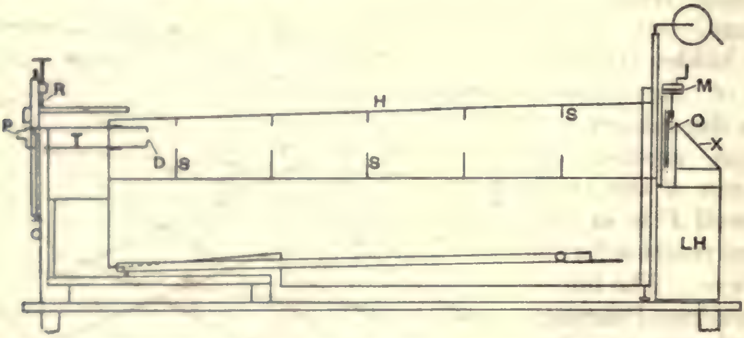

FIG. 39.—Arrangement of apparatus for the measurement of visual efficiency.

LH, lamp house; *X*, mirror to reflect light through the test object, *O*; *M*, micrometer for adjusting width of test bands in *O*; *H*, hood excluding extraneous light; *S*, velvet screens to reduce reflected light from walls of hood; *T*, telescoping member at one end of which is the diaphragm, *D*, for limiting the area of view; at the other end the artificial pupil, *P*, is placed near the subject's eye; *R*, head-rest shown in figure 32.

The artificial pupil was a round opening in a flat black surface and was 3 mm. in diameter. This size of artificial pupil was adopted as the result of a large series of observations which had been carried out previ-

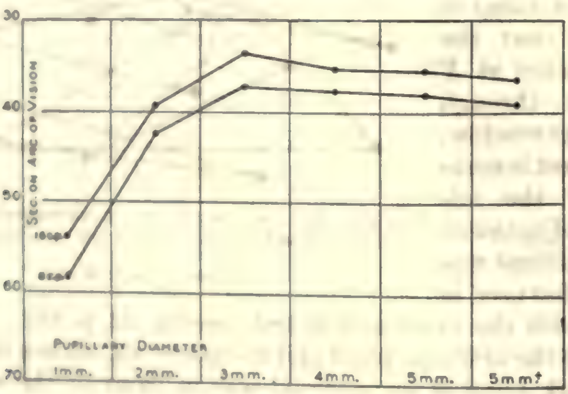

FIG. 40.—Visual efficiency with different diameters of artificial pupil.

The ordinate marked 5 mm.+ shows results when no artificial pupil was used.

ous to the present research. Data for this factor are shown in the curves of figure 40. These curves are based on about 1,200 threshold determinations on one subject, who served on different days, but under conditions which may be considered as uniform. Optimum vision is

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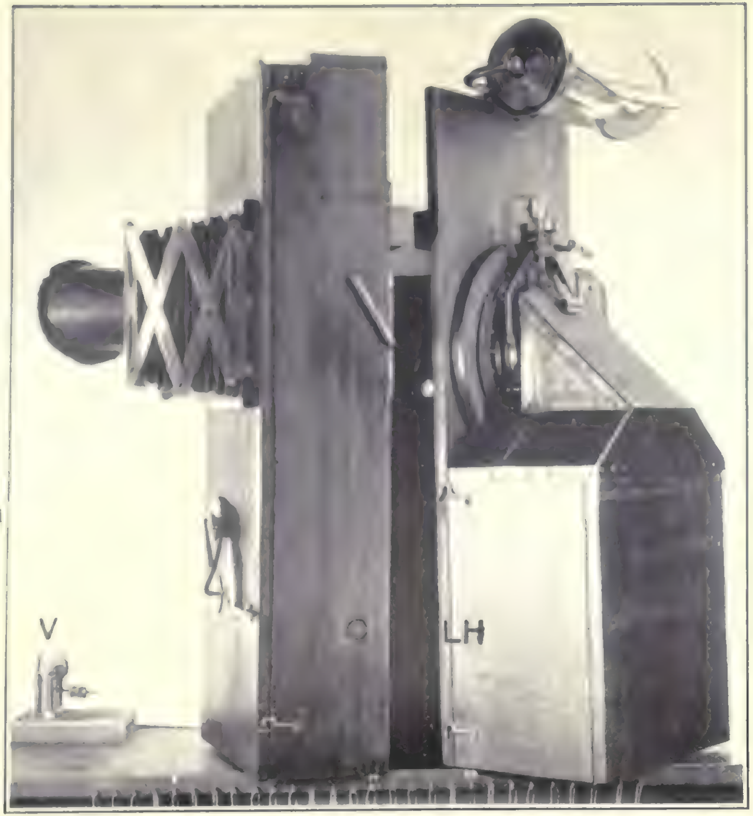

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FIG. 41.—General arrangement for shifting the visual acuity object into the position commonly occupied by the falling plate camera.

V, device for moving the camera to the left as required for photographing several eye reactions on the same plate; *C*, falling plate camera; *LH*, lamp house and visual acuity object.

FIG. 42.—Details of the visual test object, its mounting and means of illumination.

R and *R′*, two rings in which are mounted two glass gratings; *L*, three lugs to hold *R* and *R′* in position for rotation; *Y*, yoke to rotate *R* and *R′* in opposite directions against the tension of spring, *S*, when operated by the micrometer, *M*; *D*, scale of degrees for setting instrument to different axes; *C*, clamp; *B*, mirror; *G*, two plates of ground glass for diffusion of light; *X*, mirror; *W*, milk-glass window; *H*, hood for excluding outside illumination.

found to be with an opening of 3 mm., which is much better than an opening of 2 mm., but not significantly better than one of 4 mm. This agrees thoroughly with the findings published by Cobb.[1]

The falling-plate camera, which, when in use, is at the right-hand end of the hood (see *H* in the diagram in fig. 39), is so hinged that it may be swung to the left and the visual-acuity object made to take its position at the end of the hood. This arrangement is evident in figure 41. Here the camera *C* has been swung partly out, but not far enough to allow *LH*, the lamp house, carrying the visual-acuity object, to come into position. The opening at the farther end of the hood may be seen as a bright spot between the camera and the lamp house.

The test object here used for determining the visual efficiency was one in which the width of a set of alternately dark and light bands could be continuously varied without changing in any way other factors in the stimulus field. The average brightness of the field is the same for all widths of lines.

The principle upon which this type of test object is built, which allows a continuous gradation in the width of the line without changing the total light flux of the field, has been described in detail by Behn,[2] Ives,[3] and Johnson.[4] It is unnecessary to repeat details here. The essential fact is this: If two glass plates are ruled with fine parallel lines, the width of line and interspace being made the same, and the lines are filled with an opaque substance, when these two plates are superimposed in such a position that their sets of lines are not quite parallel, coarse feather-edged bands alternately light and dark and of equal width will be seen distributed over the surface when light is transmitted through both glasses. If one plate is slowly rotated in reference to the other about an axis perpendicular to their surfaces, the width and total number of visible lines will gradually change. The lines are always uniformly distributed over the field of view (see figure 51, page 186). As the angle of rotation is increased, each visible band, both light and dark, decreases in width and new bands crowd into view from each side of the field. A suitable mounting to hold two such ruled gratings and to move them under measurable conditions slowly, and in opposite directions about an axis perpendicular to their surfaces was designed by Cobb.[5] This mounting of Cobb, improved in certain particulars, is described by Johnson, who gives working drawings.[6] The test object belonging to the Nutrition Laboratory was made for us at the Nela Research Laboratory of the National Lamp Works, Cleveland, Ohio, under the kind direction of Dr. H. M. Johnson, and in

[1] Cobb, Am. Journ. Physiol., 1915, **36**, p. 335. Data are given for three subjects.
[2] Behn, Ber. d. deutsch. physikal. Gesellsch., 1906, **4**, pp. 207 ff.
[3] Ives, Electrical World, 1910, **40**, p. 939.
[4] Johnson, Journ. Animal Behavior, 1914, **4**, p. 319.
[5] Cobb, Am. Journ. Physiol., 1911, **29**, pp. 76 ff.
[6] Johnson, Journ. Animal Behavior, 1914, **4**, p. 319.

accordance with the measurements and specifications given in his article. We are also indebted to Dr. Percy W. Cobb for valuable suggestions in reference to the instrument and its use. The two gentlemen referred to can not, however, be held responsible for the form of installation which was adopted at the Nutrition Laboratory.

Some details of the test object, together with its form of mounting and means of illumination, may be seen in figure 42. Faint vertical lines appear in the test field as shown in the photograph. As viewed by a subject who is being tested, the contrast between the light and dark lines is of course much sharper than in the illustration. The separation between the lines ruled on the glass grating is $\frac{1}{240}$ inch, and the rulings, which are filled with an opaque substance, are the same width as the interspaces. The plates are held in metal rings, *R* and *R′* of figure 42. The metal rings are retained in such a position that they can be rotated on an axis perpendicular to their surface by three lugs, designated as *L* in the figure. The yoke *Y* is large enough to span the diameter of the metal rings which hold the gratings. One tip of the yoke has a bearing on *R*, while the other tip bears on *R′*. A micrometer adjustment *M* moves the yoke against the tension of the spring *S*. Thus, by turning the handle of the micrometer, the two gratings are caused to rotate slowly in reference to each other. Each grating is moved, but in opposite directions. The base which carries the micrometer adjustment, the yoke, and the metal rings for the glass gratings can be rotated so that the lines will appear in any axis desired. It can be accurately set to any axis, as degrees are marked on the scale *D*. When in the position desired, it is clamped by *C*. The test object is shown to be at the end of the hood *H*. The lamp house, which is open in figure 42, is white inside and contains one carbon filament lamp. The bottom *B* is covered with a mirror. Above the lamp are two thicknesses of ground glass *G*. In the upper part of the lamp house, along the surface *X*, is located a second mirror, which reflects the light to the milk-glass window *W*, which, when the instrument is in use, is directly behind the test field and illuminates it evenly. A soft leather washer mounted on the outer ring *R* of the test object fills up the intervening space between the window of the lamp house and the test object when in position, so that no indirect illumination interferes. The diameter of the window *W* is 10 cm.; that of the test field is slightly less than 9.5 cm.

The adaptability of the test object, which made it easily possible to present the lines in any desired axis, was a feature of merit. By working from invisibility to visibility, it was thus possible, in taking any threshold measurements on a subject, to check his observation, since he did not know at what axis the lines would appear. The micrometer adjustment was gradually turned until the subject could see lines, whereupon he called "stop" and gave the direction. If this

corresponded to the position of the test object, it was reasonable proof that the subject had actually seen the lines and had not reacted to some false impression, which, with many untrained subjects, would quite naturally be the case, provided the subject knew in what axis the lines were going to appear. The test object window was round so that a shift in the axis would produce no observable difference in its shape or position. Experience has shown, however, that an experimental difficulty is encountered when the whole window and frame are exposed to the subject.

In figure 51 (see page 186), we reproduce a full-sized photograph of the window of the test object. The bottom and right-hand edges of the figure, as well as the lower right-hand portion, have been covered with a black paper mat; the other portion shows the circular boundary of the window. If the reader will hold this illustration at arm's length it will be seen that certain parts of the boundary for the light and dark lines have particular prominence, as, for example, positions 1 and 3, as contrasted with 2 and 4. This phenomenon can not be seen in the illustrations which have been shown by Ives,[1] who figures only square areas of such striæ as are under consideration. When looking at the test field, surrounded by a definite black circular frame, it is possible, after a little practice, to sense the presence of lines and to give their direction on the basis of this intersection phenomenon where the lines form acute angles with the dark border. It is also possible to do this with smaller lines than can be seen in the center of the field. When using the test object in only one axis, as has apparently been the custom at Nela Research Laboratory, where Ives, Cobb, Johnson, Luckiesh, and others have used this test object in a number of researches, it is doubtless possible with practised subjects to instruct them to give attention only to the center of the field, and judge when lines appear there.

For the purpose of our investigation and other investigations at the Nutrition Laboratory, it seemed highly desirable to eliminate this criterion for judgment. The iris diaphragm (*D*, fig. 39) successfully solved the problem. In the apparatus as used the test object is located 170 cm. from the eye of the subject. The diaphragm *D* is 31 cm. from the subject's eye. Thus, when he accommodates for the distance of the test object, the edge of the diaphragm is very hazy and indefinite. By reducing the opening in the diaphragm to a diameter of 12 mm. and properly placing the tube and the artificial pupil in relation to the diaphragm and the test object, the subject was unable to see any of the circular frame surrounding the test field and could not see the entire field. The portion exposed to view was circular, with indefinite edges and approximately 7.5 cm. in diameter. This reduced to a negli-

[1] Ives, Abstract Bulletin of the Physical Laboratory of the National Electric Lamp Asso., 1913, 1, opp. p. 36.

gible quantity any disturbance from the phenomenon illustrated in figure 51, but with the definite boundary of the test field hidden from view, and in its place a hazy fading-out of the lines on all sides, the subject found difficulty in keeping the eye accommodated to the proper distance when lines were not in view, as just preceding the taking of threshold measurements. It was found possible to fasten a small disk of black paper 2 mm. in diameter to the surface of the glass grating which was nearer to the subject. This provided a fixation point for accommodation before the lines of the field came into view. The central line of the field directly behind the fixation point changed only in width, and a few lines on either side had but slight lateral movements. This position was, therefore, very favorable for fixation. The artificial pupil performed an important service in making a fixed viewing-point for the subject. Had it been larger, or had there been no artificial pupil, it would have been possible for him, by moving to one side or the other, to have exposed the definite, circular frame of the test field. With a 3-mm. opening of the artificial pupil, it was impossible to get in any position with the apparatus as used, from which the definite edge of the test field could be seen, and when the subject moved slightly one way or the other, he could immediately recognize the dimming of the field and that he must be out of position.

The luminant was an 8 c. p. carbon filament lamp. The brilliancy of the test-object window in candles per square meter of surface was 20.3. With a 16 c. p. carbon lamp, the brilliancy in candles per square meter was 57.8. In Cobb's apparatus the diameter of the window exposed to view was 3.5 cm. The brilliancy of the source in candles per square meter he varied from 5.94 to 189.0. Increased intensity of illumination beyond a certain point does not greatly aid the eye in distinguishing detail. Fig. 40 (p. 170), which gives results with 8 c. p. and 16 c. p. lamps, shows that although the latter supplied an illumination about three times that with the 8 c. p. lamp, yet the visual efficiency was not greatly improved. As the brighter light was much more tiresome to the eye, the 8 c. p. lamp was used in illuminating the test object for these experiments.

The first time a subject was given this test at the Laboratory he was instructed as follows:

"You will now look through this small peep-sight with the right eye and see a light window about 6 feet away from you. In the window are dark bands. Please notice that they may be made small or large as we desire. We want to discover the size of the smallest lines that you can see. Our method is as follows: We will first make the lines so small that they disappear from view; they will then be gradually widened until you can see them, whereupon you will call 'stop.' Please notice, also, that the lines may be vertical or horizontal or they may be in a diagonal (45°) position with their tops to the right or to the left. The four positions will be used, viz, right, vertical, left, and horizontal. You can never tell beforehand in what direction

the lines are going to appear, because the lines are made too small to see, and the instrument is set for some one of these four directions in a chance order. Do not try to anticipate the direction in which the lines will come. When you are given the signal to be ready, look intently at the black dot in the middle of the field. The instant you know the direction of the lines call 'stop' and give the direction. After you have done this, rest the eye by closing it until the next 'ready' signal."

The right eye of the subject was always used for the determination; it was not refracted and glasses were never worn. In these experiments it was not the object to attain absolute values or to reveal individual differences, but to test the man, for comparative purposes, against himself in successive sessions. Since the eye was not refracted it is obvious that astigmatism would play a rôle in influencing readings in certain axes. The time at our disposal for taking the measurements on a single subject was approximately 10 minutes. In this interval it was usually possible to make from 3 to 5 separate threshold determinations for each of the four positions, right, vertical, left, and horizontal. These followed each other in a chance order. After two or three trials the experimenter knew, approximately, where to expect threshold value. The micrometer wheel was, after this, advanced, at first one turn in about 5 seconds, and then the rest of the way to threshold at the rate of one revolution in 15 seconds, as the object was to get the reading within an interval of less than a minute after the subject had been given the "ready" signal and fixated on the black dot in the middle of the test field. A comparison of results from this apparatus, with standards previously established, will be considered in the discussion of our results (see page 607) for the reduced diet experiment.

It is most useful to state the threshold-test band width for any subject in terms of degrees on the arc of vision. In the Nutrition Laboratory instrument the distance from tip to tip of the yoke Y is 119 mm. The separation of the ruled lines on the glass plates is $\frac{1}{240}$ inch or 0.10577 mm. According to the formula given by Behn, Ives, and Johnson, in the articles cited, the constant for this instrument is therefore 1.573. This factor divided by the micrometer scale reading on the instrument gives in millimeters the width of the separation of the light bands. To illustrate in another way, if the micrometer wheel is set to read 1.57, measurement by a millimeter scale applied directly to the window of the test object will show that both the light and dark bands are each 1 mm. in width, *i. e.*, from the center of one dark band to the center of the adjoining light band is 1 mm. A scale-reading of 3.14 will show bands 0.5 mm. in width, and so on. In the arrangement employed the window of the test object is distant 170 cm. from the subject's eye. On the circumference of a circle with this radius an arc of 1 second = 0.008242 mm. The millimeter width of test bands just distinguishable to the subject's eye may be divided by 0.008242 to

state the threshold in seconds on the arc of vision. For example, a micrometer-scale reading of 3.14 shows bands 0.5 mm. in width. This width of 0.5 mm. represents to the subject's vision an angular separation of 60.7 seconds between the bright lines of the test field.[1]

(13) Sensory Threshold for Electric Shock.

In a series of articles, Martin has described a method for using induced current (faradic stimulation) to determine thresholds for muscle and sensory processes. He and his co-workers have used this in several researches.[2] The same method has been used at the Nutrition Laboratory with apparatus which is practically a duplicate of Professor Martin's. Two researches have been published, one by Dodge and Benedict, the other by Miles, in which the sensory threshold for faradic stimulation was a factor under investigation. According to the theory and formula given by Martin, threshold determinations taken with different resistances in the secondary circuit with the fingers of the subject should fall on a straight line when plotted. In the results which have been obtained at this Laboratory it has seldom been found that the thresholds of a subject fall on this theoretical straight line. Our difficulty may have been subjective, due to lack of careful cooperation and attention of the subject measured. On the other hand, it is not impossible that some of the trouble was instrumental or had to do with the technique. One point in the method seems particularly unsatisfactory, *i. e.*, the determination of the tissue resistance. This was done by means of balancing on a simple Wheatstone bridge. The tissue, usually the finger-tips, together with a known resistance, was placed in one arm of the bridge, and against this a variable resistance was balanced, the final adjustment being made on a slide-wire. A telephone was used as an indicator of the point of balance on this wire. As a matter of fact, a good balance-point which gives anything near silence in the telephone can never be found; the operator has to resort to balancing quality against quality in the two ends of the slide-wire. This is a very difficult proposition with the telephone as an indicator, since the telephone membrane has characteristics which make it respond to certain vibration frequencies with greater degrees of intensity.[3] When the string galvanometer was used as an indicator in the bridge in place of the telephone, the reading was far from agreeing with that obtained by the telephone. The balance in the bridge was somewhat improved by using an adjustable capacity in the varia-

[1] In practice the constant 1.573 for the instrument and the unit width 0.008242 mm. for an arc of 1 second arc, by dividing the latter into the former, combined into one factor of 191, which, when divided by the micrometer-scale reading, gives directly the angular separation of the bright bands in degree-seconds.

[2] Martin, Am. Journ. Physiol., 1908, **22**, p. 116, and 1910, **27**, p. 226; also, The Measurement of Induction Shocks, New York, 1912. See also, Martin, Porter and Nice, Psychol. Rev., 1913, **20**, p. 194.

[3] See Meyer and Whitehead, Proc. Am. Institute of Elec. Engineers, 1912, **31**, p. 1023; Kennelly and Affel, Proc. Am. Acad. Arts and Sci., 1915, **51**, p. 419.

ble arm, but even with this improvement it was quite unsatisfactory as a measurement. According to the best determination, the resistance of the tissue of the finger-tips when immersed to a depth of 2 cm. in salt solution is in the neighborhood of 4,000 to 5,000 ohms.

An effort was made to include a large resistance in series with the secondary circuit so that the tissue resistance of the fingers would be but a small fractional part and could be assumed without actual measurement. With this sort of a change it is necessary to use a stronger current in the primary coil of the induction apparatus. The sparking at the breaking of the primary circuit becomes very objectionable under this condition and a source of considerable error. Even with the larger coils it is not possible to include 100,000 ohms and still have sufficient strength of shock in the secondary circuit for purposes of stimulation. Larger induction coils were experimented with, such as those used in commercial transformers. One of these proved somewhat more satisfactory in that a large resistance, such as 200,000 ohms, could be included in a secondary circuit with the fingers and still enough strength of shock be provided for purposes of stimulation, without the necessity of increasing the current in the primary circuit to an objectionable amperage. Since the primary and secondary windings had a fixed relation to each other in this coil, the changing of the strength of the induced current would necessitate a change in the current at the primary. Theoretically, it seemed that this would also change the wave-form of the induced current.

An investigation was carried out to determine if the wave-form changed materially within the range of change in strength of primary current, which was desirable for purposes of sensory-threshold determination. In the course of this investigation it was observed that the change in wave-form of the induced current was considerable when the primary current was changed through that range which was necessary for experimental purposes. Another factor also revealed itself, *i. e.*, that the wave-form of the induced current was varied by the amount of resistance in series with the secondary. The larger the resistance placed in series, the steeper was the rise of the current curve and the less the time to the maximum and steeper the fall. In the light of these facts, many of which are well known, it seemed highly desirable to discontinue the use of induced current and to use direct-current stimulation if possible. While most threshold measurements are undoubtedly subject to a certain percentage of error, this does not warrant the use of apparatus with variable factors for which corrections can not be made.

Many arrangements for using direct-current stimulation were tried; finally a simple one was adopted. This is shown in schematic diagram in figure 43. The apparatus consists of six main items: a drop wire D; a voltmeter V; a non-inductive resistance R; a pendulum, indicated by the arrow A, for breaking the circuit at points denoted by S and S';

a control switch *C*, which is also a pole-changing switch; and non-polarizable electrodes *E*. The switches *S* and *S′* are arranged to be struck open by a pendulum moving from left to right. When struck open they remain open. It is therefore evident from the diagram that with the switches closed, as shown in the figure, the current from the drop-wire has parallel paths *P* and *P′*. Since the fingers *F* of the subject are in series with *P′*, and the tissue of the fingers has a resistance of about 5,000 ohms, the current thus goes through *P*, where the resistance is negligible as long as *S* is closed. When *S* is struck open the current is established in *P′*. This amounts to the "make" of the circuit. The duration of the shock is regulated by the distance between *S* and *S′*. When *S′* is opened the shock is ended. This provides a shock which theoretically should have as nearly as is possible a curve showing an instantaneous rise, a square top, and an instantaneous fall. The height of the shock is a function of the voltage. The amount of electrical energy actually delivered at the fingers need not concern us here, as our results are comparative. The threshold values are expressed in terms of voltage, read at the voltmeter *V*, which had an internal resistance of 33,894 ohms at 21° C.

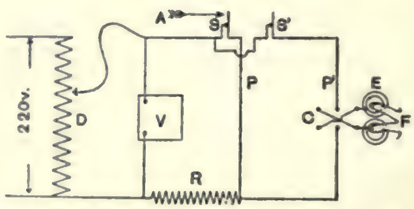


FIG. 43.—Schematic diagram of circuit for measuring the electrical threshold.

D, drop wire; *V*, voltmeter of standard make; *R*, 200,000 ohms resistance; *C*, control switch; *E*, non-polarizable electrodes; *F*, fingers of subject to be stimulated; *S* and *S′*, switches to be opened in turn by a swiftly moving pendulum represented by the arrow, *A*; *P* and *P′*, parallel paths for current when *S* and *S′* are closed.

In any such arrangement of apparatus the device used to make and break the circuit and to determine the length of the shock is of critical importance. The particular device constructed at the Nutrition Laboratory for this purpose was a modification of a similar instrument designed by the late Keith Lucas and used by him in his extraordinary researches on muscle and nerve excitation.[1] According to illustrations and description, in the case of the Lucas pendulum the contact key had to be set and the pendulum adjusted and released by hand for each stimulation delivered to the nerve or muscle preparation. It was necessary to arrange for these factors to be automatically taken care of in our instrument, the general plan of which is shown in figure 44. Perpendicular to a heavy wooden base *B*, a short stud *T* was rigidly mounted. About this an eccentric weight *E* was mounted on ball

[1] Lucas, Journ. Physiol., 1908, 37, p. 459. With this pendulum Lucas was able to secure electrical currents of any duration between 0.0001 and 0.12 second. He gives drawings showing front and side elevations of the instrument and others for detail of the contact keys. The Lucas pendulum is figured in the catalog of the Cambridge Scientific Instrument Co., England, and is listed as one of their regular pieces of physiological apparatus.

bearings so that it could revolve freely. A light aluminum arm A, fastened to the eccentric, extended from the axis of rotation a distance of 25 cm. This arm resting against a suitable catch C held the eccentric in a position above its center of gravity and ready to be tipped over to the left by the offset O carried by the wheel W. When the eccentric was lifted from the catch C, and pushed slightly past its highest position by O, which moved from right to left, it then fell of its

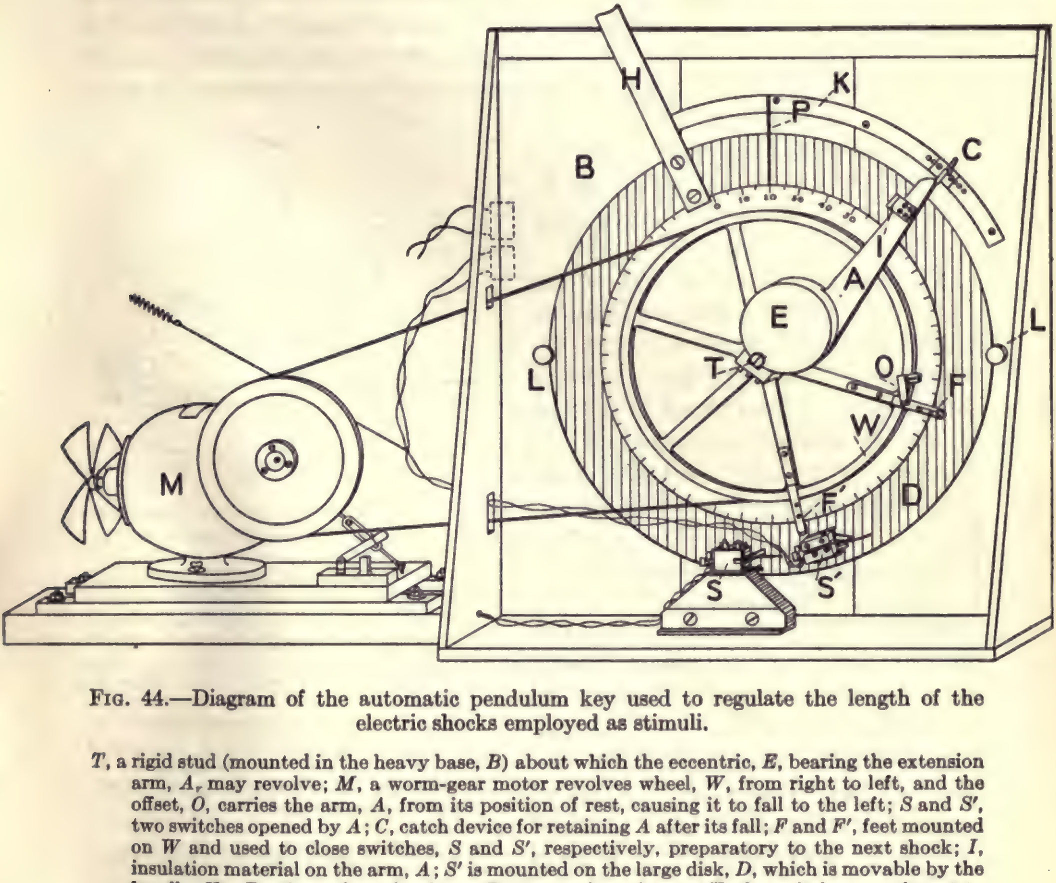


FIG. 44.—Diagram of the automatic pendulum key used to regulate the length of the electric shocks employed as stimuli.

T, a rigid stud (mounted in the heavy base, B) about which the eccentric, E, bearing the extension arm, A, may revolve; M, a worm-gear motor revolves wheel, W, from right to left, and the offset, O, carries the arm, A, from its position of rest, causing it to fall to the left; S and S', two switches opened by A; C, catch device for retaining A after its fall; F and F', feet mounted on W and used to close switches, S and S', respectively, preparatory to the next shock; I, insulation material on the arm, A; S' is mounted on the large disk, D, which is movable by the handle, H. By the scale and pointer, P, mounted on the arc, K, the switches may be set to certain degrees of separation and the disk clamped by lugs, L. The relative size of the instrument may be gaged by the size of the disk, D, which is 46 cm. in diameter.

own accord and with a very swift movement, opened the two switches S and S', and carried through to the catch C. The contacts at S and S' were so devised that when struck open they remained in this position unless released by pressure from the feet F and F' carried by the wheel W. The contact S was closed by the foot F and was always closed before S' so as to reestablish the short circuit P, figure 43. The con-

tacts were thus closed and in proper position before the offset O picked up the arm of the eccentric at the beginning of its second revolution. The wheel W was driven from a variable-speed, worm-gear motor M, which was arranged to run silently. The contact S had a permanent mounting. S' was mounted on a metal disk D. This also carried a scale giving degrees, and moved about the axis of the stud T. It was kept in position and could be clamped by the lugs L and L and moved conveniently by the handle H. The position of this movable disk determined the distance between the contacts S and S', and thus the duration of the electric shock. A hard block of insulating material I, mounted on the arm A, provided against electrical connections between the two contacts when the pendulum should swing past them. A pointer at P, secured to the arc K, indicated the degrees of separation between the switches.

The essential detail of one of the contacts opened by the moving pendulum is made clear in figure 45, which is a drawing of the back of S in figure 44. The block of rubber R, about which the contact device is built, is 33 mm. square and 26 mm. thick (vertical direction in the figure). In mounting it is secured to a metal plate m by posts and nuts n and n'. The two parts of the contact, a and b, are shown at the left. Only the binding-post for b is visible in the drawing; this is at the extreme right. a, the movable part which is struck back by the arm of the pendulum is held in metal supports at x and y. Good electrical connection with this moving portion is assured by the spring l, which also normally serves to hold the contact surface of a against that of b. A steel spring s is so located and held in definite position by pointed screws, which press into appropriate openings at one end, that when a is moved forward by the pendulum it can not return into contact with b, as would naturally be caused by the spring l, since a is caught on the detent d of the spring s in the position shown in the figure. It is retained here out of contact with b until the foot f passes over the plunger p, depressing the spring s and releasing a, so that it reestablishes good contact with b. The apparatus is arranged so that the contact between a and b is made in the switch S some time

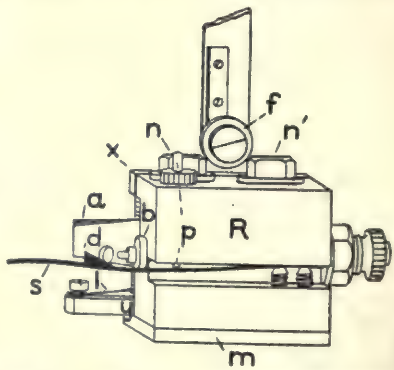


FIG. 45.—Detail for one of the contact devices struck open by the pendulum.

R, rubber block 33 mm. square and 26 mm. thick; m, metal base for securing block by posts and nuts, n and n'; b, fixed part of contact; a, movable portion of contact fastened in metal parts, x and y; s, spring with detent, d, to catch and hold a after it is struck back from b by pendulum; f, a foot which depresses plunger, p, which in turn depresses d, allowing a under the impulse of the spring l to return into contact with b ready for the next pendulum stroke.

before the contact is reestablished in switch S' (fig. 44). This precaution insures that when the switches are close together, that is, when a short-duration interval is used for the electric shock, the unavoidable chatter at reestablishment of contact in the switch S will not cause extra shocks to reach the tissue under examination.

To avoid extraneous induction effects and disturbances from other electrical conductors and from the capacity of the earth, the electrical circuit shown in the diagram in figure 43 should be as compact as possible. The total length of wire, other than the drop-wire and the resistance which was employed in the circuit should be as short as is at all compatible with the other conditions desired for the measurements. The pendulum key was used in the same room with the subject, who was about 10 feet distant from it. The noise made by the action of the device is thus a factor to be considered when it is used for threshold

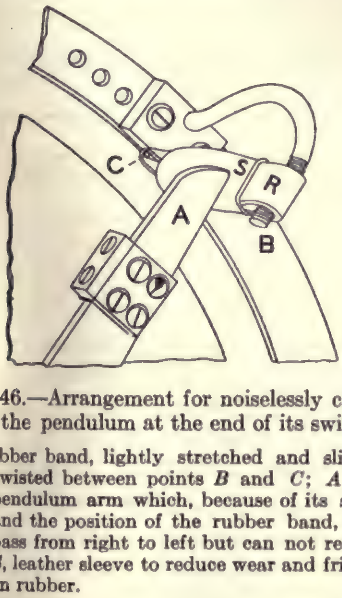


Fig. 46.—Arrangement for noiselessly catching the pendulum at the end of its swing.

***R*, rubber band, lightly stretched and slightly twisted between points *B* and *C*; *A*, the pendulum arm which, because of its shape and the position of the rubber band, may pass from right to left but can not return; *S*, leather sleeve to reduce wear and friction on rubber.**

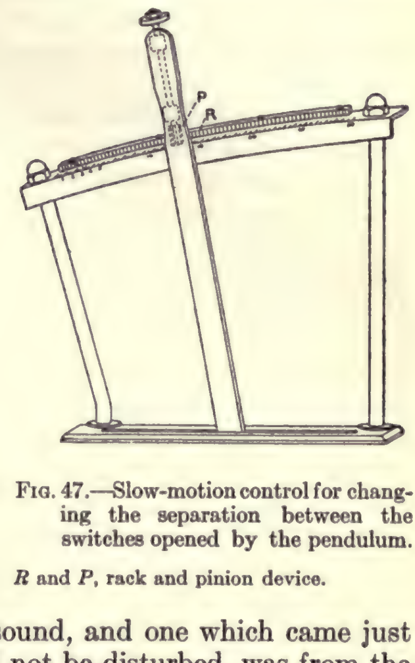


Fig. 47.—Slow-motion control for changing the separation between the switches opened by the pendulum.

***R* and *P*, rack and pinion device.**

determination. The most annoying sound, and one which came just at a moment when the subject should not be disturbed, was from the catching of the pendulum after it had opened the switches. At such a time the pendulum produced a very objectionable thud when the catch was made of metal. Finally a simple and very satisfactory arrangement was found, the detail of which is shown in figure 46. A rather heavy 2-inch rubber band R is lightly stretched between two points, B and C, and held in a slightly twisted position. The rounded end of the arm A, swinging up from the lower right-hand corner as shown in the figure, can easily pass under, but having passed, can not return. A soft leather sleeve S encircles the band and greatly diminishes the wear

on the rubber. It also decreases the resistance which must be overcome by the arm A in passing under. The sleeve tends to roll on the rubber band; the position of wear is thus continually shifted. This form of catch is without objectionable sound and, in fact, is almost noiseless.

The handle H, shown incomplete in figure 44, extends 75 cm. beyond the periphery of the disk and, passing through a table above the pendulum, is arranged for slow movement with a rack-and-pinion device as shown in figure 47 (see R and P). By this means the separation of the switches S and S' (figure 44) may be continuously and accurately varied if desired. In the reduced-diet investigation the separation of the switches S and S' was always the same, 5°, representing a shock duration of about 0.0035 second, and only the voltage was changed. It is of course evident that the voltage might be held constant and the threshold determined by changing the duration of the shock by shifting the position of S' with the slow-motion control of figure 47. Unpublished experiments have shown that a threshold may be determined in this way.

The electrodes which were used for this measurement recommend themselves for several reasons. In the first place, it is of prime importance in making sensory measurements with the fingers as receptors that the hand should be in a normal and comfortable position. The arm should be supported, the hand relaxed, the fingers should not be required to span from one vessel of solution to another in such a way that the muscles are tense and must be frequently rested. The form of the electrodes employed in the present research and the convenience of their application may be seen in figure 48. A two-compartment glass vessel (pickle-dish), each compartment 8 by 9 cm. in area and 2.5 cm. deep, was suitably supported at a level conveniently below that of the armrest. Soft pads were provided which the subject could arrange under the palm of the hand according to his own desire and comfort. Two fingers could very easily be placed in the salt solution, one on either side of the narrow glass partition. Two porous clay cups, one located in each compartment, contained a saturated solution of zinc sulphate. Amalgamated zinc rods were also placed in the porous cups. Thus the electrodes were comfortable and non-polarizable. The liquid could be brought to body temperature and easily controlled by the small electric heater which was located below the electrodes. Another point in favor of these electrodes, involving considerable economy of time, was that the area of each compartment was sufficiently large in comparison to the volume of the finger-tips immersed in them to make it unnecessary to adjust the height of the solution for each subject. The depth of immersion employed was 2 cm.

Figure 48, which has just been described, shows the fingers of the subject in position for stimulation. In figure 49 the hands of the

FIG. 48.—The non-polarizable electrodes for the finger tips with means of controlling the temperature.

The natural and comfortable position of the subject's hand is evident.

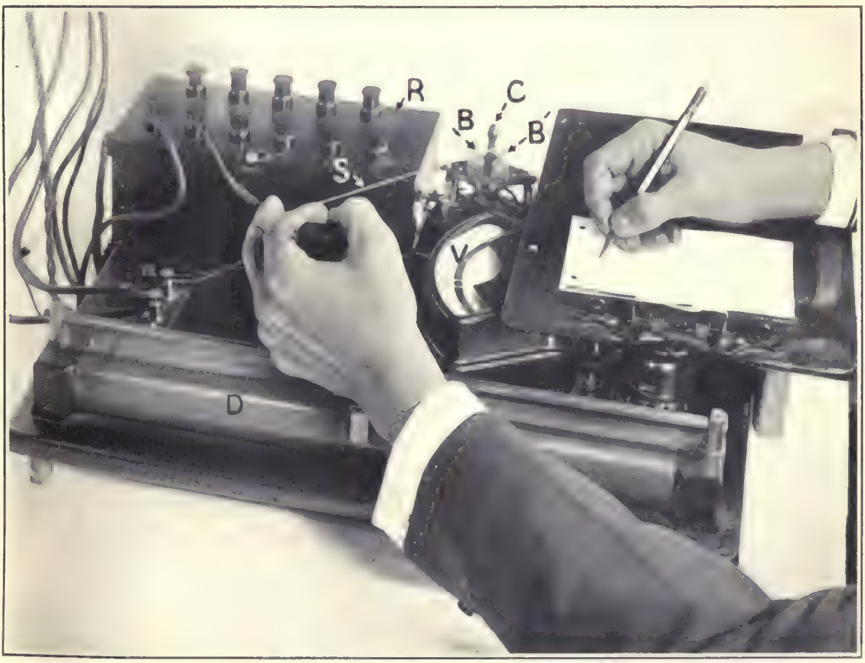


FIG. 49.—Apparatus for controlling the voltage of the shocks and for intermittently short-circuiting them.

D, drop wire across 220 volts; *V*, voltmeter of standard make; *R*, 200,000 ohms resistance; *C*, control switch; *B* and *B′*, vacuum bulbs (parts of control switch), each containing 1 c.c. of mercury, which are noiselessly tipped back and forth to make and break the circuit. *S*, conveniently placed cord for operating *C* in breaking the circuit; a spring not visible in the illustration exerts tension on *C* in the opposite direction from *S*. The hands of the operator are shown in position for taking electrical threshold measurements.

operator are shown in position for taking the threshold measurements. This apparatus and the hands of the operator are of course entirely hidden from the subject who is being tested. The apparatus in figure 49 is as follows: A drop-wire *D* is composed of 750 turns, with a total resistance of 490 ohms, rated for constant use at 0.7 amperes. Fine adjustments in voltage may be made by the large handle which is seen grasped by the left hand. *V* is a voltmeter of standard make and *R* a non-inductive resistance, 1 megohm in 10 steps; 200,000 ohms were employed. The control switch *C* is a modified form of Durig switch, the modification consisting chiefly in the shape of the glass vacuum bulbs *B* and *B′*, through the ends of which platinum wires extend. The contact is completed inside each bulb by 1 c. c. of mercury. In this switch the bulbs have been curved so that when it is in a neutral position the mercury is definitely away from the platinum points in each end of the tubes. It is a polarity-changing switch, and by having the tube bent in this fashion the current may be broken without establishing it in the opposite polarity. The switch is exceedingly quiet in its action, and for this cause highly recommends itself as a psychological apparatus. As employed in these experiments and illustrated in the figure, the platinum wires in the near ends of the glass tubes were disconnected, so that when the switch was tipped to the operator's left the circuit was broken and could not be established in the opposite polarity. By a suitable spring the switch was normally held in the position shown. This completed the circuit for the subject's finger and the shocks were delivered at the tissue. When the switch was tipped by pulling on the string *S*, which could be done by a simple movement of one finger of the operator's left hand, the circuit to the subject was noiselessly broken and the shock did not reach his fingers. In this way the observations of the subject were checked and controlled. The action of this control switch in no way varied that of the pendulum, which continued to be operated by the motor at its regular intervals.

When a subject came the first time for this measurement he was instructed in the following words:

"Our task now is to discover how small an electrical shock you can feel. Understand, the shocks will be very small indeed; none of them will be painful. In fact, most of them will be so small that you will have to give closest attention to feel them at all. In the beginning they will be strong enough so that you can feel them rather easily. From this strength they will be made gradually weaker and weaker. Your problem is to attend as carefully as possible and respond every time you feel a shock by pressing this button in your left hand. The shocks are produced by the action of this pendulum. You will notice that a shock comes in a particular relation to the noises which the pendulum makes. The shocks will never come at any other time but just at that position, so when you hear the 'click,' 'click' of the pendulum, as if it said 'ready, now,' then attend very carefully and respond if you feel the shock. The shocks will not always come through to your fingers; there are some blanks when no shocks are given. Of course you will be unable to

tell the difference between blanks and those times the shocks are too weak to be felt, so your only problem is to give most careful attention and respond every time you believe you feel the shock. Let your hand and fingers be relaxed and as comfortable as possible. The tips of the fingers should rest lightly on the bottom of the glass vessel. You may find it best to look at the hand during the experiment."

The operator first made a rapid survey to ascertain the range of the threshold. After this he recorded the voltage of every shock and whether or not it was responded to by the subject. He also recorded the position of blanks, several of which were used with every series, and he indicated if the subject responded at such times. If the subject was right-handed, the first and second fingers of the right hand were usually employed as receptors. If there happened to be an abrasion on one of these fingers which would be immersed in the salt water, another finger was substituted.[1]

(14) Speed of the Eye Movements.

The subject's task in this measurement was to look from one to the other of two marks successively and as rapidly as possible throughout a period of 5 seconds. The two fixation marks were definite and prominent and separated by a distance which amounted to 40° on the subject's arc of vision. The left eye was covered, the fixation-points being visible only to the right eye. The eye movements were recorded by Dodge's familiar photographic technique.[2] The apparatus was the same as that used for recording the eye reactions and the subject occupied the same position (see figs. 30, 32, and 35). The ground plan of the apparatus is indicated by figure 50; the subject occupies a position at *E;* one fixation mark is at *R*, to his right, the other at *L*. The angle subtended between these two marks is 40°. The mark *R* was always in position; *L* was placed in position when the eye-movement measurements were to be made. It was mounted on a screen *F*, which could be raised out of the way of the stimulus device for the eye reactions, as can be seen in figure 35, page 165. The frame *2* in figure 50 is the same as *2* in figure 35. When this was released and fell by the action of the small solenoid shown in the latter figure, it exposed fixation-point *R*, and this was the signal for the subject to look from *R* to *L* and so begin his series of movements. At the moment that *R* was exposed the beam of light was turned on the subject's eye and the photographic record was commenced. The beam of light was reflected from mirror M_1 to mirror M_2 just below the lens *Z*, and from this second mirror to the cornea of the subject's eye, from which it reflected back through the lens and through the hood of the camera *H* to the falling plate as indicated by the arrows.

[1] In using the fingers for electrical threshold determinations, as outlined, an abrasion causes usually a great reduction in the threshold, since the shock is felt at this point and commonly has a painful quality.

[2] Dodge and Cline, Psychol. Review, 1901, 8, p. 145; also Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, pp. 151 ff.

The subject very easily understood his task. He had to be especially warned, however, to hold his head still by keeping it pressed firmly against the rest and biting on the soft wooden peg with his teeth. He was repeatedly told that he must make his eye do all the moving and that he should see one mark clearly before looking for the other. The subject was instructed also to refrain from winking at the time of moving

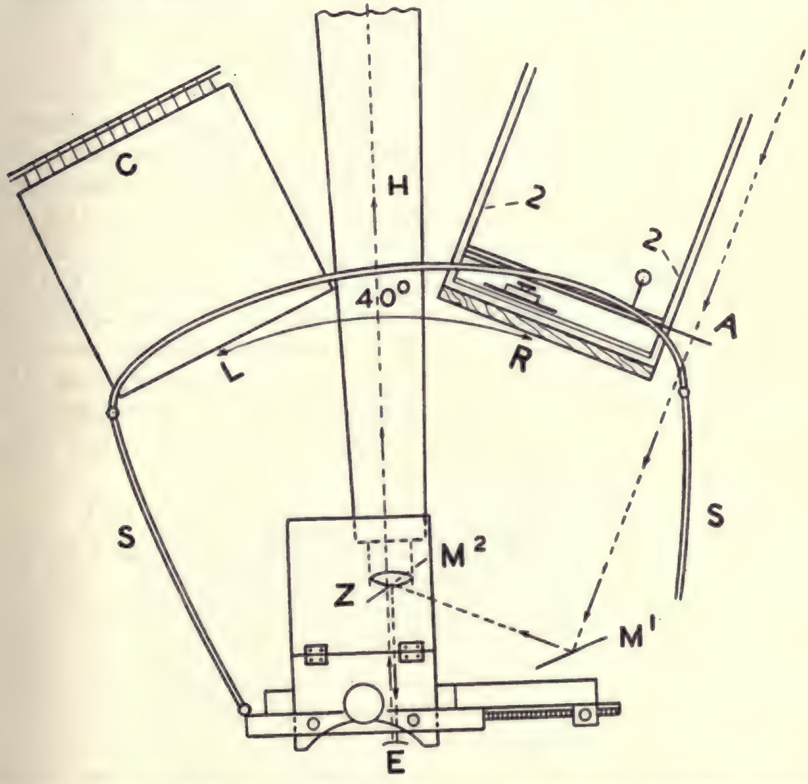


FIG. 50.—Ground plan of the apparatus and arrangement for photographing eye movements.

S, black screen surrounding the subject's field of view; *R* and *L*, right and left fixation marks separated by 40°; *H*, hood of camera; *Z*, lens in front of subject's eye, *E*; M^1 and M^2, mirrors for reflecting beam of light indicated by arrows; 2, frame carrying shield, *A*, drops down and exposes eye to light as signal for movements to begin; *C*, cords for operating eye-reaction, stimulus device. The camera, located at the other end of the hood *H*, is not indicated in the diagram.

the eye.[1] The black screen which enclosed the subject's field of view (*S*, figure 50; *B*, figure 35) was of particular service in eliminating all distracting objects, so that it was unnecessary to warn the subject to refrain from looking at other objects than the correct fixation-points.

Two series of movements were recorded on each photographic plate. The camera was moved slightly to one side at the beginning of the sec-

[1]Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 81.

ond record, so that the tracings would not overlap sufficiently to make them illegible. Two plates were taken for each subject, giving a total of four series of movements. A plate from each of two subjects may be seen in figure 52. The records are to be read from the bottom upward. The subject's eye movements were along a horizontal line, the plate moving downward at right angles to the line of eye movement. Right and left indicated in figure 52 corresponds with *R* and *L* of figure 50. They are of course reversed since the record was taken through a lens. In beginning a series of movements the subject looked for an instant at the right-hand mark *R* after it was exposed; then the eye was moved to *L* at the left. A corrective movement was frequently necessary to direct the vision definitely at the fixation mark. The dashes between the fixation-points were caused by the time-interrupter in the beam of light, each dash and one interspace equaling 0.01 second. The corrective movements in the record of the left-hand plate show that this subject was unusually accurate in his fixation of the marks. The other man sacrificed accuracy for speed. In spite of instructions the subject who made the records in the right-hand plate did not accurately fixate the marks in turn. The difference can be clearly brought out by laying a rule along the left-hand boundary of these records. The fixation marks should fall on a straight line, which they closely approximate in the left-hand records.

(15) Speed of the Finger Movements.

Finger-movement records were taken both evening and morning. This test is a rather simple one to arrange and to perform, and it has proved itself useful in earlier investigations at the Nutrition Laboratory.[1] The apparatus, method, and form of the record for this measurement is readily understood from figure 53, which is a schematic representation of a part of the apparatus shown in figure 31, page 160. The exposure apparatus *E* (fig. 31) has been disconnected, unclamped, and withdrawn. The subject's hand clasps the post *P;* his arm is comfortably supported at S. The lower part *A* of the lever system used for recording the muscle-thickening of the patellar reflex is removed and a light, adjustable, but rigid connection *W* is placed (fig. 53) between the metal recording-point *R* and the finger at *F*. A small rubber band about the finger between the first and second joints forms an easy connection with *W*, which is adjustable in length, its longer portion being a very light-weight wooden member for purposes of insulation from the high tension sparks.

The high tension terminals of a transformer *T* of commercial design are connected with the frame of the kymograph and the metal recording-point *R*. A suitable current (0.7 ampere) from a 110-volt D.C. source is used on the low-tension side of the transformer. A contact *C* in this

[1] Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, pp. 167 ff.; Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 84.

The intersection of the dark and light bands with the border is more prominent at positions 1 and 3 than at 2 and 4. By this intersection phenomenon, many subjects are able to judge correctly the axial direction of bands before being able to see them at the black fixation dot in the center of the field. See p. 173 for method of avoiding this difficulty.

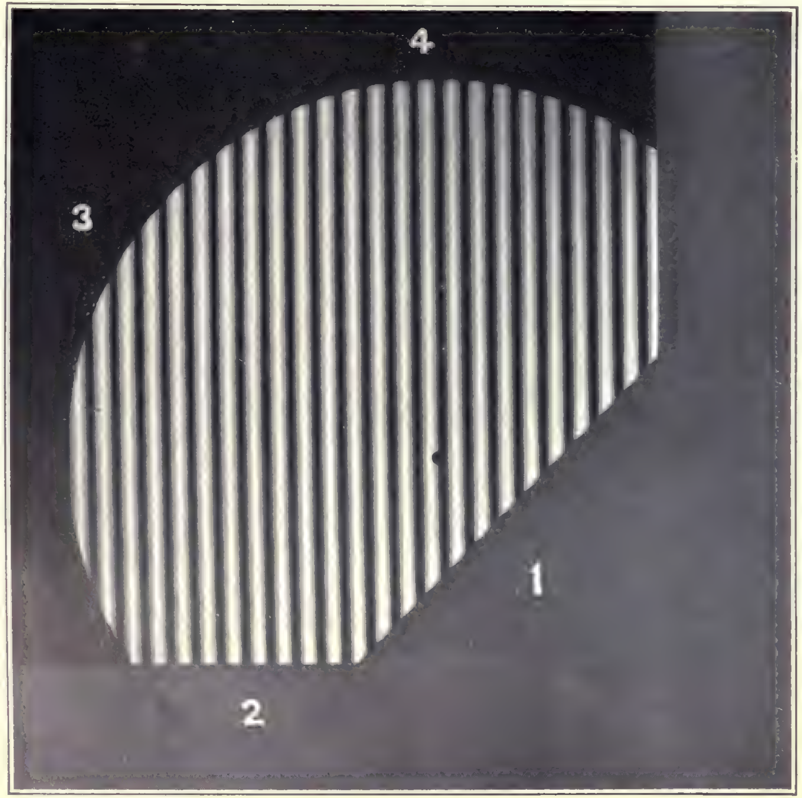


FIG. 51.—Full-size reproduction of a portion of the visual-test object window.

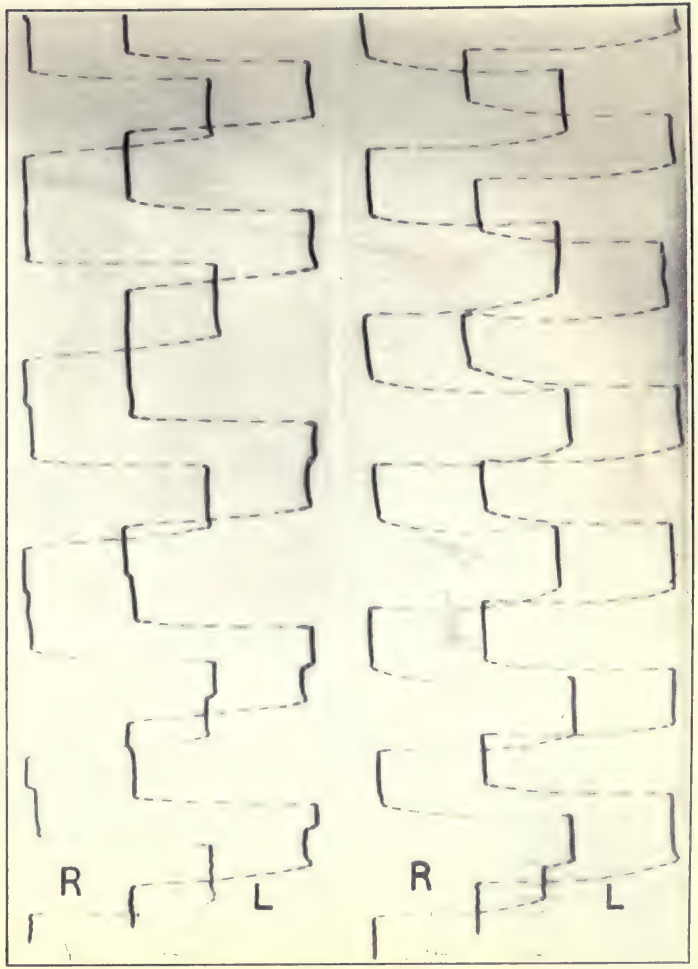


FIG. 52.—Sample eye-movement records, unretouched, reproduced nearly full size from contact prints of the original plates.

circuit is opened every 2 seconds by the swing of the pendulum in a large Seth Thomas clock. When the clock pendulum opens the contact in the primary circuit, a spark from the tip of the metal pointer dislodges the smoke in the immediate vicinity on the kymograph paper, and so incorporates time intervals directly with the record. The speed of the kymograph drum *D* was 50 mm. per second, and as its periphery represents the distance of 500 mm., it was convenient to make the finger-movement series 10 seconds long. Movements were counted in five 2-second blocks. Three series of movements were recorded, with a rest interval of at least 1 minute. Ten sec-

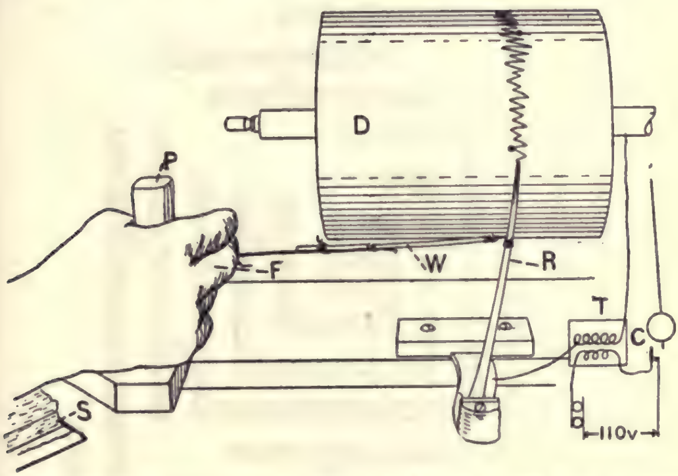


FIG. 53.—Schematic representation of apparatus and hand in position for recording finger movements.

S, support for wrist and arm; *P*, post to be gripped; *F*, finger connection to recording point, *R*, by insulation material, *W*; *T*, induction apparatus of commercial design with high tension winding connected to kymograph drum, *D*, and metal recording point, *R*; *C*, pendulum of large clock to break primary circuit of transformer and so, by the jump sparks, record time directly on the finger movement record.

onds at maximum finger movement speed is not so long as to be fatiguing. The subject was allowed to use whatever amplitude of movement he thought consistent with his best performance. The tracing was to be a record of finger movements and not of hand or arm movements. For this cause the subject was instructed to grip the post *P* rather tightly. The first and second fingers of the hand were moved together simultaneously, a form of movement which Langfeld[1] has shown favors the greatest speed. Sections of finger-movement records may be seen in figure 29, page 158. It was experimentally expedient to place the finger-movement records on the same kymograph sheet with the others taken in room B. They could be traced over the word reactions without causing any particular

[1] Langfeld, Psychol. Review, 1915, **22**, p. 453.

difficulty in later counting the finger movements or measuring the reaction time. The subject used right or left hand as desired, but the same hand in all sessions. The apparatus was in full view while the record was made. The small "make" and "break" sparks from the transformer could be seen jumping from the recording-point. There was every opportunity to rest the hand from strain of position during the intervals between records, when the subject's attention was taken up with other matters.[1]

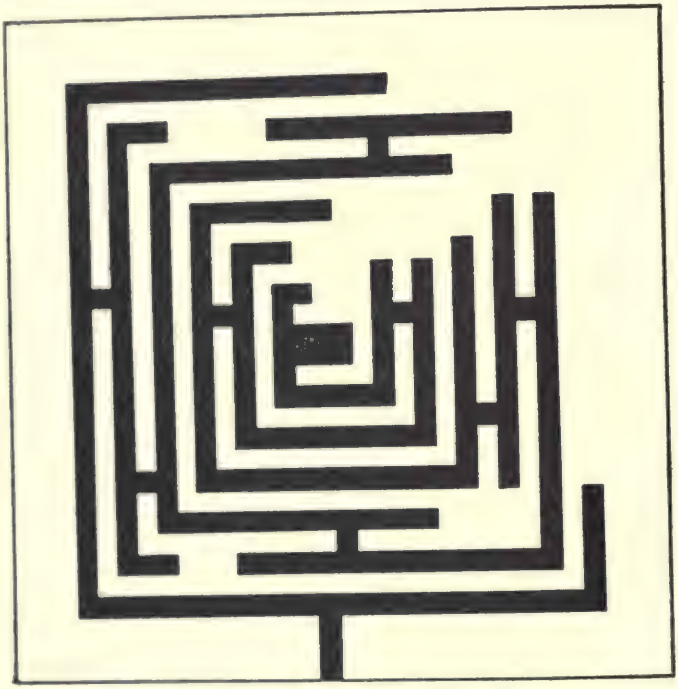


Fig. 54.—The form of the right-angle maze.

The subject began in the center and worked outward on the black pattern.

(16) Efficiency in Traversing a Right-angle Maze.

In connection with another research, a complete description of which is not likely to be published, it was desired to provide a motor test in which the subject, while looking at something which corresponded to a map, would be required to carry out a series of movements in accordance with definite rules. For this purpose two identical right-angle

[1] Previous to the reduced-diet research, finger-movements of the same nature were taken at the Nutrition Laboratory in other connections. These were recorded photographically, the arm and hand supported by the adjustable rest shown at the left of the subject in fig. 22, p. 152. The fingers were connected to two light systems of levers, which may be seen in front of the camera. Electrocardiogram pulse records were taken at the same time and incorporated in the same records. Sample records of this character may be seen in other publications (Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 96, fig. 11; Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 171, fig. 28.)

mazes were constructed. From two aluminum sheets, 3 mm. in thickness, paths were cut 6 mm. wide and arranged as the black design in figure 54. The exact form of the pattern did not seem of prime importance; the one selected was a form which had been used by Boring in a learning experiment.[1] The two longest paths in the pattern shown at the extreme left and bottom were each 16 cm. long. A particular effort was made to have the sides of the paths smooth and even. When completed, the two mazes, *A* and *B*, were mounted, one directly above the other (see fig. 55). The lower maze, *B*, was completely inclosed, except for an opening in the front, which was so placed as to be convenient to the hand of the subject. As the subject looks down on the upper surface of the box the lower maze, and the hand when in position, were completely hidden from view. The vertical clearance

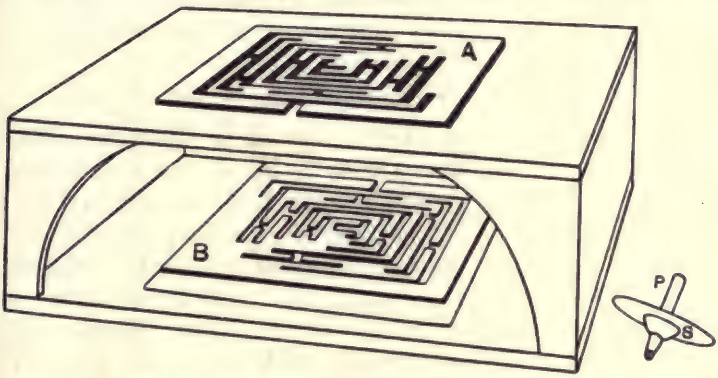


FIG. 55.—The maze-tracing apparatus.

A and *B* are two mazes of identical size and pattern. *A* is rotated 180° on *B* and mounted above *B* in position for the subject to take the test of tracing *B* while looking at *A*. The subject has full knowledge that he must move the pencil opposite to the directions indicated on *A*. *S*, a wide rubber shield on the pencil, *P*, makes it impossible to place the finger at the pencil's point.

space inside the box above the lower maze was 11 cm. This was ample space for the hand of the subject. A short blunt pencil *P* was fitted with a wide, stiff rubber shield *S*, 7 cm. in diameter, and this made it impossible, when the pencil was properly held, for the subject to place the tip of his finger at the tip of the pencil, which might otherwise be done for purpose of orientation. This pencil was taken in the right hand and placed in the center of the lower maze. The forefinger of the subject's other hand was placed in the center of the upper maze, *A*, the one which was visible to him. It was then explained that the two sets of paths were of identical pattern, but that the one below had been rotated 180°, so that every motion indicated in the set of paths above must be exactly reversed for the set below. The problem was to escape from the maze below as quickly as possible, being guided by watching and

[1] Boring, U. S. Government Hospital for the Insane, 1913, Bulletin No. 5, p. 51.

tracing the maze above. The subject was warned to let the movement above accompany or be in advance of the movement below and to *keep the rule of reversal constantly in mind.* The subject worked as fast as he desired, but if he got lost, instead of wandering on blindly (the typical method in solving the usual maze problem) he was instructed to ask for a new start from the center. The total time was taken from the first start to the successful finish. A paper beneath the lower maze was marked by the pencil and showed the subject's progress. This record was used solely for control to prove that the proper path was followed. The test has the added advantage that it can not be conveniently practiced outside the Laboratory, as can mirror drawing or writing. Thus we have here something different from a typical maze experiment, but for convenience of description it may be so classified. Naturally the test could be partially learned in successive trials. At each laboratory session the subject traced completely through one time. He was not allowed outside practice.

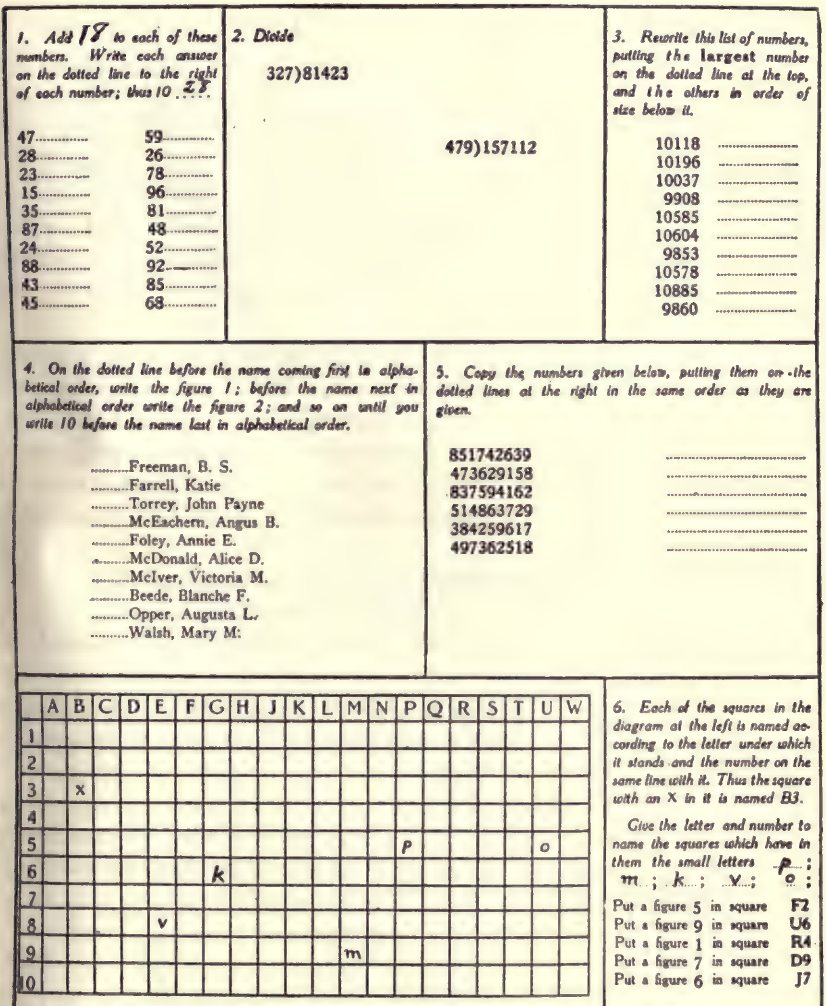
(17) Efficiency in Performing Certain Clerical Tasks.

Dr. F. Lyman Wells suggested to one of us the possibility of using clerical tests as a measure of the individual's condition and general efficiency in the present research. He had developed but had not described a test blank for this purpose (see fig. 56), and very kindly supplied us with blanks for the first three experimental sessions.[1] This gave us time to have several forms of this blank made up for use in the experiment. A zinc cut was made for the general form including the instructions for each of the six tasks with the lettered and numbered squares in the lower left-hand corner (see fig. 56). Six mortises were made in this cut. The copy was set up on linotype slugs which were made of suitable lengths for the various openings in the zinc plate. The type used was 12 point Antique for numbers, and 10 point Old Style for letters and words.[2] Enough copy was made for each kind of material to permit the printing of 6 different blanks. Most of the copy was taken from Dr. Wells's blanks. The blanks which were made up from the zinc cuts had to be prepared by hand in certain particulars. In task No. 1 the amount to be added to each of the numbers had to be written in and the illustration filled in. In task No. 6 the small letters other than *x* had to be filled in the squares by hand. A form with openings at the different squares insured accuracy in doing this and made it a very simple matter to prepare a set of blanks ready for use. The six different blanks were numbered in a secret way so that the subject had no satisfactory means of remembering or designating them. The same blank

[1] This test should be known as the "Wells Clerical Test C," inasmuch as other test forms of the same general abilities were developed in connection with it. This material, Captain Wells informs us, will be taken up again as soon as opportunity is afforded; it was ready for serious application at the time of his entry into Government service.

[2] The legibility of numbers and words may be judged from figure 56, bearing in mind that the orginal blank from which the reproduction was made is 19 by 23.5 cm.

was not used successively with the same squad. On the back of the blank was a suitable space for name and date, and here were printed also some general directions. These directions were the same with all blanks and were mainly serviceable only the first time the subject took



1. Add 18 to each of these numbers. Write each answer on the dotted line to the right of each number; thus 10 ..28..

47........	59........
28........	26........
23........	78........
15........	96........
35........	81........
87........	48........
24........	52........
88........	92........
43........	85........
45........	68........

2. Divide

327)81423

479)157112

3. Rewrite this list of numbers, putting the **largest** *number on the dotted line at the top, and the others in order of size below it.*

10118 ....
10196 ....
10037 ....
9908 ....
10585 ....
10604 ....
9853 ....
10578 ....
10885 ....
9860 ....

4. On the dotted line before the name coming first in alphabetical order, write the figure 1; before the name next in alphabetical order write the figure 2; and so on until you write 10 before the name last in alphabetical order.

........Freeman, B. S.
........Farrell, Katie
........Torrey, John Payne
........McEachern, Angus B.
........Foley, Annie E.
........McDonald, Alice D.
........McIver, Victoria M.
........Beede, Blanche F.
........Opper, Augusta L.
........Walsh, Mary M.

5. Copy the numbers given below, putting them on the dotted lines at the right in the same order as they are given.

851742639 ....
473629158 ....
837594162 ....
514863729 ....
384259617 ....
497362518 ....

	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T	U	W
1																				
2																				
3		x																		
4																				
5														p					o	
6							k													
7																				
8					v															
9												m								
10																				

6. Each of the squares in the diagram at the left is named according to the letter under which it stands and the number on the same line with it. Thus the square with an X in it is named B3.

Give the letter and number to name the squares which have in them the small letters p....; m....; k....; v....; o....;

Put a figure 5 in square F2
Put a figure 9 in square U6
Put a figure 1 in square R4
Put a figure 7 in square D9
Put a figure 6 in square J7

FIG. 56.—"Wells Clerical Test C."

A form of blank arranged by Dr. F. Lyman Wells for testing clerical efficiency. The test was entirely ready for serious application at the time of Dr. Wells's entrance into Government service. He has not had an opportunity to describe it, but kindly granted us its use in the present research.

the test. The total amount of time which the subject required to complete all the clerical tasks was taken by the assistant. The six tasks were to be performed in the order as numbered, and as quickly and accurately as possible. The time required was usually less than 15

minutes. If the tasks were correctly performed, a total score of 100 points could be made.

In a later chapter the data will be given for the preceding 17 neuro-muscular and psychological measurements. No tests were tried and discontinued.

STATE OF NUTRITION.

With adults the demand for food is of two kinds. First, there is the temporary demand which is determined in large part by idiosyncrasy, by appetite, the season, the variety of the supply, and the environment. This is in large part psychological and has fully as much to do with the quality of the food and manner of serving as with the amounts actually eaten. Second, in comparison with this we have the permanent demand as represented by the total amount and energy content of the food eaten rather than by any transitory changes resulting from whims of appetite or individual caprice.

The body requires food to meet its needs for repair and maintenance and to keep the weight at the normal level. When there is a persistent loss in body-weight, this is an index that too little food is being taken. When there is a persistent gain, too much food is eaten. Just what is the best weight for the normal adult will be discussed subsequently, but with any weight, deviations are produced by either too much or too little food.

Food is also required by the body to maintain its usual state or plane of nutrition. When the body has been educated to living upon a high nutritional level, there is a distinct demand for food to maintain this level. When it has been educated by necessity or otherwise to a lower level for a long time, the question arises: will the return of a plethora of food supply affect the food habits or will there be a tendency to maintain the low level?

Finally, the dietetic habits reflect in large part the state of euphoria or well-being of the individual. If he does not feel well, he usually eats less. With free selection of food, man usually eats until he feels satisfied and is quite disinclined to eat less than will produce this feeling. Frequently to secure this he eats a larger amount than he needs.

Undernutrition, as commonly interpreted, implies not only loss of weight, but frequently emaciation to such a degree that it is visible, even to an alarming extent. Pathologists, on the other hand, state that undernutrition may exist without ocular evidence of waste. This is not so conflicting as may at first appear, for it is increasingly evident that by undernutrition must be understood not merely the loss of a visible proportion of fat to body-structure, but also a disturbance of the state of well-being of the neuro-muscular organism, thus affecting the efficiency. Any dietetic régime which produces this disturbance may, in the absence of an obvious pathological lesion, for purposes of discussion at least, be termed undernutrition.

POPULAR BELIEFS REGARDING THE STATE OF NUTRITION.

Two decades ago people who were highly colored and plump, even to excess, were popularly regarded as looking healthy and vigorous. More recently, the general trend of popular opinion has been somewhat away from the earlier point of view, and to-day there is reasonable doubt in the minds of the laity as to whether or not a stout person is as healthy as one of average weight. On the other hand, there is a strong belief that to be thin is a sign of ill health. Such individuals are considered as undernourished or half-starved, less efficient, and less able to withstand either severe work or disease than their better-nourished competitors.

One of the difficulties immediately experienced in attempting to classify individuals as "underweight" or "undernourished" is the fact that even in the language of medical experts the differences are not clearly indicated. Personal conferences with eminent medical examiners and actuaries lead us to the belief that there is no sharp distinction between these two stages. Individuals who are underweight would have been, a decade ago, classified as undernourished, but with the increasing belief that underweight is not necessarily disadvantageous to health, medical examiners are rather disinclined at the present time to consider mere underweight as an index of undernourishment unless supported by other evidence. Still, it is the popular belief that the best efficiency is obtained from men who are well nourished rather than from those who are underweight; thus the distinction between "undernourished" and "underweight" is not readily made.

It is likewise difficult to state quantitatively what is meant by a fat, medium fat, thin, or moderately thin person. The best practice at the present time uses the average weight of individuals for a given height, age, and sex, and ordinarily indicates differences of 5, 10, or 15 pounds over or under weight, without statement as to whether or not the persons are undernourished. It is quite clear, also, that the general build of the body must be taken into consideration, for if an individual is tall and extremely thin he might be classified as undernourished, particularly if the frame is very broad. Still, in the absence of a more exact classification, it is sufficiently satisfactory to use the average weight and indicate, in accordance with the best actuarial usage, whether the person is over or under weight in terms of plus or minus 5 or multiples of 5 pounds.

BODY-WEIGHT AS INDEX OF FOOD REQUIREMENT.

The body-weight is dependent upon the food intake on the one hand and the oxidation of food or body-material on the other. The majority of adults retain their body-weight almost without change for years, if not decades. This is the more surprising when one considers the great number of foods available and the variety in nature, quality, and quan-

tity of foods, these changing with the season and geographical location. Furthermore, even with individuals who live a regular life, the muscular activity varies considerably. With so great changes in the factors influencing the body-weight, this practically constant balance between food intake and consumption of material in the body, with no great storage of material or drafts upon previously stored material, leads one to conclude that the majority of individuals so select their diet as to meet their physiological needs, as far as the total fuel content of the food is concerned.

Since in this monograph the factor of growth is not to be considered, it is only necessary to discuss the food requirement for keeping the body in condition for the needs of daily life. The body-cells are continually undergoing metamorphosis and disintegration and hence must be repaired. In addition there are temporary drafts upon stored body-material. This is obvious when one considers that the combustion of material is continuous, while the food intake is only intermittent. Many individuals take food only twice a day; in the interim, particularly in the early morning hours, the combustion of material in the body must be largely that which has been previously deposited in the form of either glycogen or fat. With exercise these drafts upon body-material may be even greater, but the compensation is rapid; in fact, after severe exercise large amounts of food are usually consumed, so that the delicate balance between intake and output is even then maintained.

TRANSITORY VARIATIONS IN BODY-WEIGHT.

In judging of the adequacy or inadequacy of a diet, transitory variations in body-weight should not be emphasized unduly. The body contains a large proportion of water, which may be very rapidly lost or gained. In pathological cases, with edema, very large amounts of water may be stored in the body. With normal individuals, the most striking examples of variations in weight which are without significance as indicating actual loss of body-tissue occur with athletes during severe muscular exercise. Professor William G. Anderson,[1] of the Yale University Gymnasium, states that a football player in 1 hour and 10 minutes of exercise lost 6.4 kg. It is not uncommon for Marathon runners in 3 hours of running to lose 3.9 kg., while a member of a college boat crew in a 22-minute race is known to have lost 2.5 kg. An analysis of this loss, based upon the known metabolic activities during severe muscular work, shows clearly that in so short a period as 22 minutes it would be utterly impossible to have disintegrated 2.5 kg. of either protein, fat, or carbohydrate. In experiments with a bicycle rider riding to the limit of human endurance, with a runner, or with a man walking, it has been found that 200 grams of carbon dioxide per hour represent

[1] Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, p. 96.

approximately the maximum excretion. This would correspond to not far from 100 grams of dry organic material, or about one-quarter pound. In instances like these the body-weight is very rapidly regained inside of 48 hours, showing that the large changes in body-weight were chiefly due to fluctuations in water content of the body.

With the average individual leading either a sedentary or a moderately active life the same holds true, although in less degree. Frequent weighing on delicate scales throughout a 24-hour day shows a tendency for the body-weight to fall, with recovery when food or drink is taken, and sharp loss when urine or feces are passed.[1] Hence fluctuations in body-weight that appear from day to day have practically no significance, and only the average weight for a week or more is of practical value. A progressive loss in weight extending over 7 or more days indicates that drafts are being made upon organized body-tissue and not simply upon the water content of the body. Failure to recognize this fact has frequently led to erroneous assumptions regarding the adequacy or inadequacy of a given diet. An individual may not vary in body-weight or may even increase in weight and yet actually lose body-substance because of an inadequate diet. This can be readily seen when we consider that with diets predominatingly carbohydrate there is a strong tendency for the body to retain water, while with diets predominatingly fat there is a distinct tendency for the body to lose water.[2] Under these circumstances the use of the body-weight as an index of the adequacy of the fuel value of the diet is open to grave criticism—a criticism that can be overcome only by continuing the observation throughout several days, if not weeks.

The fact that the large majority of adult individuals retain their average body-weight constantly for long periods of time is, as stated, *prima facie* evidence of the adequacy of the diet from the fuel standpoint, and a strong indication that the appetite instinctively adjusts the intake to the needs. Accordingly, since there is this automatic adjustment of intake to needs, we are primarily interested in the need for fuel rather than in the actual food intake and are particularly interested in the fuel demands of the ordinary individual, what determines them, and to what extent, if any, they may be decreased. In addition to the abstractly scientific side of this problem we had at the time of the investigation a question of tremendous and immediate national importance, since any scientific study of the fuel needs of the body which would contribute towards the solution of the possibility of decreasing the need for fuel required immediate investigation. The fuel need of the body may be considered from one point of view as that required for the maintenance of vital activity at its lowest ebb under normal

[1] See Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, fig. 1, p. 90.

[2] Benedict and Milner, U. S. Dept. Agr., Office Exp. Sta. Bull. 175, 1907, p. 225. Also cited by Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, p. 92.

conditions, *i. e.*, "basal metabolism," plus the fuel required for extraneous muscular activity. The latter varies with the external activity of the individual, for obviously the sedentary college professor requires much less energy in his diet than the Canadian lumberman.

Since basal metabolism has not, at present, known, definite relationships to the state of well-being and the efficiency of the organism, other criteria for judging the adequacy of the state of nutrition must be employed. The condition of the fundamental physiological processes and of the more complex neuro-muscular processes which have a most intimate bearing upon muscular and mental work are determinable by well-attested laboratory techniques and in any comprehensive investigation should be considered.

BASAL METABOLISM.

The minimum demand for energy is the amount which is required for the "basal metabolism." The chief factors known to increase the vital activity or metabolism of the body are muscular activity and ingestion of food. If the former is precluded by enforced repose and the latter is eliminated by observing the metabolism when the active processes of digestion have ceased, *i. e.*, with the subject in the post-absorptive state, we obtain a value which may be considered to be the basal metabolism of that individual.

While in this measurement of the basal metabolism the influence of muscular activity and food are eliminated, there are other factors which produce variation in the basal metabolism of normal individuals. Among these the most obvious is body-size, as indicated by height and weight. Age also influences the metabolism, for elderly people of exactly the same height and weight as younger people have a somewhat lower basal metabolism. There is strong evidence that during deep sleep the metabolism is perceptibly lowered. Severe muscular work unquestionably has a stimulating after-effect upon the metabolism which may persist for many hours after the work has ceased. Furthermore, careful measurements of the basal metabolism over a considerable period of time show that variations of no mean magnitude occur even with the same individual, these averaging at times as high as 13 to 14 per cent.[1] The exact cause for these variations is not known. That they are seasonal is highly improbable. Suitable analysis of the correlations for weight, height, surface, age, and other factors which influence the metabolism can only be made from measurements obtained with a large number of normal individuals.[2]

CONSTANCY IN BASAL METABOLISM.

The possibility of the basal metabolism being a physiological constant has been much discussed. From the earliest measurements of

[1] Benedict, Journ. Biol. Chem., 1915, **20**, p. 263.
[2] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919.

the metabolism of man and animals, investigators have attempted to find if uniformity existed in the metabolism of different human individuals and even different species of warm-blooded animals. In the experiments made with the respiration calorimeter at Wesleyan University direct measurements of the heat production of man were made for the first time and the complete uniformity of direct and indirect calorimetry was first established. In common with other investigators at that time, no attention was paid to the importance of controlling the minor muscular activity in the restricted confines of the respiration chamber. The data obtained in these measurements were carefully searched to find if evidence existed of uniformity in the metabolism of individuals. It was soon found that with individuals inside the respiration chamber, living substantially the same routine of life, the metabolism was relatively constant with the same individual from period to period. This was made the subject of discussion by one of us in conjunction with Dr. T. M. Carpenter,[1] but even at this time differences in individuals, and particularly in individuals of different weight, were strikingly emphasized.

Recourse was had by earlier writers to the comparison of the metabolism on the basis of per kilogram of body-weight, on the theory that a large animal would give off more heat than a small animal, and heat production per kilogram would thus be a better index than heat production per individual. This, of course, is based upon the arbitrary assumption that each kilogram of weight has the same heat-producing power. Although for general purposes the heat production per kilogram of body-weight was found to be reasonably constant, many writers were of the opinion that the heat production per square meter of body surface was a much better index than the heat production per kilogram of body-weight. For such comparisons the body surface was computed by the now archaic method of Meeh,[2] using the formula $12.312 \sqrt[3]{\text{body-weight.}^2}$ Much of the evidence implied that the discrepancies between individuals were in large part eliminated when the calculations were based upon body-surface. Indeed, many writers considered that they were so completely eliminated as to establish a "law of surface area."

The so-called "law of surface area" has had a rather remarkable history. Warm-blooded animals have a temperature which is usually much higher than the environment. It was argued that heat was lost to the environment in proportion to the extent of the body-surface and that for equal surfaces the heat loss would be very nearly the same. In other words, since the heat produced inside the body very nearly compensates for the heat lost, thus resulting in a practically constant body

[1] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 126, 1910, p. 105.
[2] Meeh, Zeitschr. f. Biol., 1879, **15**, p. 425.

temperature under all conditions of external environment, the natural inference was that the heat production was determined by the heat lost, and the heat lost was, in turn, determined by the number of square centimeters of surface exposed to the environmental temperature. The early promulgation of this idea by Rameaux[1] and later by Bergmann,[2] unsubstantiated, it is true, by experimental evidence, was followed in 1883 by a series of remarkable experiments by Rubner,[3] who altered the environmental temperature and studied the basal metabolism under these conditions. The law of surface area, as finally enunciated by Rubner, and almost simultaneously by Richet,[4] was to the effect that the heat production of warm-blooded animals is essentially proportional to the surface. So attractive did this general thesis appear that E. Voit[5] made the claim, based upon computations and fragmentary metabolism measurements on various animals, that this law held true whether the living organism was a horse or a hen. In other words, he computed that approximately 1,000 calories per square meter per 24 hours were given off by an animal. This figure became so fixed in the minds of physiologists as to be almost a fetish, and every effort has been made to utilize it for practical purposes, particularly in the comparison of pathological measurements with "a normal standard."

The desirability of having a standard figure for comparison with pathological cases admits of no argument. That such a standard figure actually exists is, however, open to serious argument, for it requires the assumption that there is a constant basal metabolism per unit of body-surface. Furthermore, the advocates of the law of surface area give little recognition to the fact that at least 25 per cent of the heat produced during conditions of repose is lost by the vaporization of water from the lungs and skin, warming of the expired air, etc.

One difficulty in interpreting metabolism data has been the lack of a sufficient number of individuals who have been studied under comparable conditions to provide values with the high degree of accuracy required for the deduction of such important factors as the relationship between the heat production and the body-weight or the heat production and the body-surface. Recently values obtained with over 150 men and women were brought together and charted.[6] These measurements were made for the most part in the Nutrition Laboratory, and all were secured with the subjects in complete muscular repose and in the post-absorptive condition. The general picture

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[1] Rameaux, Bull. Acad. de méd., Paris, 1838–39, **3**, p. 1094; Bull. Acad. roy. d. sc. de Brux., 1839, **6**, p. 121; Mém. Couron. Acad. d. sc. de Belgique, Brux., 1856–58, **29**, 64 pp.

[2] Bergmann, Über die Verhältnisse der Wärmeökonomie der Thiere zu ihrer Grösse, Göttingen, 1848.

[3] Rubner, Zeitschr. f. Biol., 1883, **19**, p. 535.

[4] Richet, La chaleur animale, Paris, 1889. His earlier writings are here summarized.

[5] Voit, Zeitschr. f. Biol., 1901, **41**, p. 120.

[6] Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 139; Benedict, *ibid.*, 1915, **20**, p. 263.

presented by these values was far from indicating constancy. As would be expected, large men as a rule produced more heat than small men and large women more than small women. But when the calculations were made on the basis of per kilogram of body-weight, it was found that the heat production even on this basis varied for the men from 19.7 to 32.3 calories, with an average value of 25.5 calories. Nearly one-third of the observations fell outside of the extreme limits of plus or minus 10 per cent. Thus, on the basis of per kilogram of body-weight, there appeared to be no evidence with a sufficient degree of constancy to establish a "law."

Closer analysis of certain of the figures showed that in a group of athletes practically no values were found in the lower range, and that the heat production for the group lay for the most part somewhat above rather than below the average value of 25.5 calories per kilogram of body-weight. The measurements obtained for the women indicated a lower metabolism per kilogram of body-weight than the metabolism of men of corresponding height and weight. Like comparisons on the basis of per square meter of body-surface showed similar lack of constancy. From these values, therefore, it would be perfectly legitimate to conclude that athletes as a class have a somewhat higher metabolism than non-athletic individuals of the same height and weight and that women have a somewhat lower metabolism than men. Thus, we have the first definite proof of differences in the metabolism of different classes of individuals.

This lack of constancy in metabolism is further confirmed by an examination of all our data obtained throughout many years of experimenting, new-born infants, young children, youths, and elderly individuals alike indicating very considerable variations from the so-called standard or normal figures. In recent years the attempt has been made to recognize these variations and to replace the single standard by a convenient scale of standard figures which should take into consideration age and sex. This is certainly a step in the right direction, but must be looked upon as a preliminary to the abolishment of the surface-area law. An extensive biometrical treatment of the basal metabolism data obtained in the Nutrition Laboratory is in press. From these data a series of tables has been derived which may be used for the prediction of the probable metabolism of men and women of varying weights, heights, and ages.

METHOD OF PRESENTING DATA FOR BASAL METABOLISM.

While there has been much quibbling over the method for presenting the data for basal metabolism, some writers stoutly maintaining that a basal metabolism determined in short periods should be expressed in values per half hour or per hour, the fundamental computation of basal metabolism must, in the last analysis, deal with the 24-hour period.

Furthermore, a great many people spend over one-half of their time either in bed or sitting quietly with minimum muscular activity. Since sitting involves an increase of but 10 per cent above the basal, a considerable proportion of the 24 hours of the day may be properly represented either by basal metabolism or by a slight percentage above it.

For the great needs of this Nation the fundamental basal metabolism per 24 hours is a factor of prime importance. For the physiologist the basal metabolism has even a greater refinement of definition. Theoretically, the basal metabolism is the minimum metabolism, but this is rarely observed in man, and the minimum metabolism compatible with life may be very much lower than the ordinary basal metabolism of a normal individual. However, it is commonly assumed that the basal metabolism, measured during periods of complete muscular repose, 12 hours after the last meal, and with the subject in deep sleep, represents the minimum, normal basal metabolism. The factors influencing this may be divided into two classes: (1) extraneous or superimposed factors, such as muscular work and the ingestion of food, and (2) inherent factors, such as sex, age, composition of the body (proportion of muscular tissue), condition of sleep *versus* awake, and disease. Many of these may pertain to the same individual at different periods of life. In studying groups it is important to note the influence, if any, of sex, age, state of being awake or asleep, and also the composition of the body, *i. e.*, a study of individuals who are distinctly fat as compared with those who are distinctly thin. Finally, there are ever-increasing data with regard to the influence of disease upon metabolism, but the opportunity is infrequent for studying this with a single individual, for rarely can a subject be observed in health and again subsequent to acquiring a disease, such as diabetes and hyperthyroidism. One must therefore resort to a study of groups of normal individuals and compare the results with groups of individuals having the disease. But a study can be made with a single individual on the influence of sleep, the digestion of food, and muscular work. All three factors influence metabolism in an increasing degree. So, by insisting upon complete muscular repose and the absence of food, the two most prominent factors influencing basal metabolism are eliminated. There is still left sleep. Thus far the studies on metabolism in deep sleep are extremely few and are practically limited to observations with the respiration-chamber method.

VARIATIONS IN NUTRITIONAL LEVEL.

An analysis of the factors affecting metabolism shows that the influence of food and muscular work is always in the same direction, *i. e.*, to increase metabolism. Are there any conditions in which metabolism can be depressed? In other words, is the basal metabolism

capable of any material alteration? Are there variations in it? If so, how wide, and can conditions be imposed upon the body so as to lower the basal metabolism? It is very clear to students of metabolism at the present time that one of the greatest factors in metabolism is the stimulus to cellular activity which is continually acting upon the body-cells. Can the stimulus be lowered? It has been shown by giving a carbohydrate-free diet, thereby developing an acidosis, that the acids do stimulate the cells to greater activity, with a resulting greater metabolism. Is it possible to reverse this condition? The normal existing stimulus consists of acids, chiefly amino, flowing through the blood-stream. It is conceivable that by reducing these amino acids, providing the theory of acid stimulus is true, the basal metabolism may be markedly lowered.

In the subsequent discussion special emphasis will be laid upon those features of the research that contribute to the question of the factors relating to cellular stimulus, most marked among them being the withdrawal from the body of rather large amounts of nitrogen, as indicated by the pronounced negative nitrogen balances found with all of the subjects.

It is indeed surprising that after 15 years' search for a nutritional level with man markedly different from that of the normal individual, such a level should not have been found in all the researches conducted by this and other laboratories. With animals other than man, changes in the nutritional level are by no means uncommon in nature. One has but to think of the long period of hibernation of such mammals as bears, during which the metabolism is sustained, although at a very much lower level than normal. With marmots it has been shown that the body temperature is also much lower than normal. In other words, during hibernation we have animals approaching the cold-blooded stage. Prior to hibernation there is a large accumulation of fat; during hibernation there are, of course, drafts upon body-material to sustain life, even at the lower metabolic level. It is furthermore worthy of note that with bears, at least, the birth of young occurs during hibernation.[1] It would seem to be a provision of nature that these animals born during hibernation have an extraordinarily small birth-weight. Instances are not uncommon of bears weighing over 500 kg. having young with a birth-weight of 500 grams. Furthermore, after birth there is a relatively long period of suckling, in which the bear cub subsists wholly upon its mother's milk, this period occurring entirely during hibernation. This small birth-weight in proportion to adult weight—a proportion that we believe exists nowhere else among mammals—is unquestionably a minimizing of drafts upon body-material during hibernation.

[1] Personal communication from Dr. C. Hart Merriam, Washington, D. C.

With other animals and, indeed, with fishes, pronounced changes in nutritional level are frequently observed, particularly prior to the breeding season. Thus Parker[1] specially emphasizes the prime condition of the bull seals in the Pribilof Islands at the beginning of the mating-season. Throughout this time, according to Parker, no food is taken and the physical combats of the mature animals in the various rookeries are very fierce; at the end of the breeding-season the bulls are distinctly in a depleted muscular condition.

"The bulls, as a result of their incessant activities, are in a state of extreme emaciation. Many of them have been on the beaches from May, and during the period between the time of their arrival and the end of July or early part of August, they touch no food. This fast of well over two months, coupled with their incessant activity, drains them of all their stored energy. Their fat disappears and they are reduced almost to skin and bones. In this state they may be driven off a rookery without resistance and they soon return to the sea to begin the winter migration. During this period they feed and fatten in preparation for the coming season."

Miescher's notable observations[2] on the migration of the salmon in the Rhine and the severe drafts upon muscular tissue primarily made for transformation into testicular or ovarian tissue are all called to mind as provisions of nature for marked transitions in nutritional level. Thus, Miescher shows that the salmon, after coming to the Rhine from the sea, virtually starve. Yet the generative organs of both male and female develop greatly, this being at the expense of the muscles, which may lose 55 per cent of their weight. Even after 5 to 15 months' fast in fresh water, during which time they lay their eggs, Miescher found fat globules in the muscle-cells of salmon.

In addition to the classical work of Miescher, to whom we have been indebted for practically all of our knowledge on the composition of the migrating salmon, it is a great pleasure now to be able to cite two especially fine pieces of American research, that by Greene[3] and more recently that by E. D. Clark and L. H. Almy,[4] who fully confirm and extend Miescher's observations.

In view of this adjustment to conditions, it is somewhat surprising that the popular conception of emaciation and nutritional level should be so antagonistic to any reduction in body-weight. In reality, there is no biological reason why there should not be at least a periodic change of considerable degree in the nutritional level with man. Since these changes in the nutritional level may have profound significance in reproduction, judging from the lower animals, it thus becomes impor-

[1] Parker, Scientific Monthly, May, 1917, p. 393.

[2] Miescher-Reusch, F., Statistische und biologische Beiträge zur Kenntniss vom Leben des Rheinlachses im Süsswasser, Internat. Fischerei-Ausstellung, in Berlin, 1880, p. 154; see also Miescher-Reusch, Die histochemischen und physiologischen Arbeiten, Leipsic, 1897, p. 116. Cited by Clark and Almy, Journ. Biol. Chem., 1918, **33**, p. 497.

[3] Greene, Journ. Biol. Chem., 1912, **11**, p. xviii; see also same journal, 1918, **33**, p. xiii.

[4] Clark and Almy, Journ. Biol. Chem., 1918, **33**, p. 483.

tant in making as comprehensive a study as practicable of the welfare and general physical condition of man to include observations of possible influence upon reproductive processes.[1]

Nature has thus provided for material changes in the nutritional level, and particularly for possibilities of long drafts upon body-material either with deficient nutrition or during complete fasting. But there is likewise (among animals, at least) a pronounced rise in weight on the return to normal feeding after the prolonged drafts. For instance, immediately after hibernation, the bears begin to eat voraciously and accumulate a storage of fat preliminary to the next season's hibernation. The seals proceed to their feeding-grounds and return the following year in prime condition. This recovery of weight after hibernation or after low nutritional level must be considered likewise in this study with men. Fortunately, our observations throw some light upon the rapidity of return to body-weight after a prolonged period of reduced diet and contribute materially to this question.

It would appear that with humans those individuals who are accustomed to frequent or relatively frequent fasting have a distinct tendency to increase in weight. The excessive eating following restricted diet has been noted in a great many places. One of us, on a visit to Petrograd, was informed by Professor Pawlow that the sale of the artificial gastric juice prepared in the Laboratory of Experimental Medicine was relied upon in large part to sustain the experimental laboratory. Prior to the war, Russian fast days were very frequent, and Professor Pawlow remarked that if one plotted the Russian fast days and also the sale of artificial gastric juice, it could be seen that peaks in the curve of the sale of gastric juice invariably followed a few days after each fast day. In other words, after fasting the Russians ate voraciously; this produced digestive disturbance and they would then purchase the gastric juice for therapeutic purposes. Our own experience with a number of the subjects of the low-diet research bears out in general these experiences, *i. e.*, that following a period of restricted diet there is a distinct tendency toward overeating and like-wise toward a rapid and frequently a sustained increase in body-weight.

The experiences of athletes likewise tend to show that after a period of athletic training with restriction in diet and severe muscular exercise there is a proneness to take on considerable weight. Nevertheless these conditions have been so commonly overlooked by physiologists that, so far as we are aware, no specific studies of metabolism have been made for these apparent variations in nutritional level with man, or such simple indices of metabolism as pulse-rate and blood pressure recorded under these conditions. In the following chapters we purpose discussing the effects of a prolonged reduced diet and its accompanying

[1] See page 638; also Miles, Journ. Nervous and Mental Disease, 1919, **49**, p. 208.

state of nutrition upon the various physiological and psycho-physiological processes of a group of men.

To tabulate the results of this research and prepare the material for publication would have been an impossibility without the intense cooperation of Miss Annie N. Darling, to whom the editorial revision of the entire manuscript has fallen; of Mr. William H. Leslie, who, as chief of the computing division of this Laboratory, has untiringly labored to secure both rapid and accurate tabulation of the results; and of Miss Elsie A. Wilson, who has unremittingly labored on much of the abstracting, as well as the computing and tabulating. Our obligation and gratitude to these cooperators is extreme. Mr. Leslie was ably assisted by the Misses Frances E. Kallen, Anna M. Burns, Marion L. Baker, Mary D. Finn, Mildred J. L. Manning, and Helen C. Waldron. The drawings used in this report were for the most part the result of the skilful attention of Messrs. Edward L. Fox and Alden K. Dawson.

DISCUSSION OF RESULTS.

BODY-WEIGHT.

According to our general plan of research, observations were to be made upon these men, first, during a period of insufficient food, and second, during a period of maintenance diet at a lower nutritional level. The most obvious result of a reduction in the amount of food taken is the loss in body-weight caused by the fact that body-reserves are drawn upon to supplement the inadequate diet. Outside the physiological laboratory, therefore, no method is so satisfactory for determining differences in nutritional level with special reference to drafts upon or storage of body-material as long-continued observations on the body-weight. Carried over a period of several days, if not weeks, these are truly indicative of the state of the body-reserves. A careful study of the body-weights of our squads, both prior to and subsequent to diet reduction, is therefore of importance.

To shorten the preliminary period of insufficient food in which the subjects were brought to the lower nutritional level, it seemed desirable to reduce the body-weight of the men as quickly as possible. The reduction of body-weight has been the subject of a great deal of investigation, and many practical methods have been suggested and extensively applied. These fall for the most part into a few well-defined classes. First, the body-weight may be rather rapidly reduced by complete fasting. During the 31-day fast made in this Laboratory the body-weight fell about 1 pound for each day of complete fast, although the loss was much more pronounced in the earlier part of the fast than in the latter part. A second method is to reduce materially the food in the diet. By giving less food than is actually required, the deficiency is made up by drafts upon the body-material. Third, the reduction in

body-weight is accomplished by excessive exercise. In other words, by keeping the food intake at a constant level and by increasing the demands for energy, the body-weight may be reduced. Fourth, the body-weight may be rapidly lowered for specific short periods by the use of purgatives. Fifth, in addition to exercise and practice, a popular method of reducing weight has been to take very hot baths or to induce profuse perspiration by excessive clothing. Undoubtedly this removes a considerable amount of water from the body, but it has practically no influence upon the organized tissue.

The method of losing body-weight by changing the character of the diet has, we believe, never been used, although there is no particular reason why this should not be successfully employed. When the carbohydrate in the diet is in large part replaced by fat, it has been quantitatively demonstrated by Benedict and Milner[1] that there is a very considerable discharge of water from the body, apparently held by the carbohydrate previously ingested. Undoubtedly this condition is accompanied by a considerable reduction in glycogen content of the body, and glycogen is known to hold considerable quantities of water.

In order not to complicate the problem by producing excessive loss in weight due to drafts upon body material as the result of excessive muscular exercise, the simpler form of weight reduction resulting from insufficient food, with approximately constant muscular activity, seemed the best procedure. Our problem here, as stated earlier, is a study of the influence of insufficient food and not primarily the study of a loss in weight as a result of excessive exercise. This latter factor presents certain problems that of themselves should receive special experimental treatment. In the first part of the study, a combination of two methods was used with some of our subjects in that the reduction in diet was combined with excessive muscular activity, as these subjects, especially those light in weight, found it difficult to reduce upon the general diet supplied to the squad. Our records show that in certain cases very considerable activity was engaged in to secure the reduction in weight, since all the men were informed at the beginning that they were supposed to reduce their weight 10 or more per cent.

NORMALITY OF INITIAL BODY-WEIGHTS.

The initial body-weights of these men are of interest as showing whether they were normal or above or below the normal weight. As would appear natural, it was easier for a man who was above normal to lose weight than a man who was under normal weight. If the selection of subjects could have been made on the body-weight basis and an equal number of men over and under normal weight chosen, the con-

[1] Benedict and Milner, U. S. Dept. Agr., Office Exp. Stas. Bul. 175, 1907, p. 225; abstracted by Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, p. 92.

ditions would have been ideal. Such a selection was impossible; but a number of the men in Squad A were under the normal weight at the beginning of the experiment. For the purpose of showing the relationship between the actual weights and normal standards, we have collected the body-weights of the men in Squads A and B and have compared them with the so-called normal weights given in a medico-actuarial mortality table.[1]

Although precautions were taken in all instances to weigh the men under exactly the same conditions[2] as to the absence of food in the stomach and after a night without drinking-water, nevertheless the possibility of retention of urine, and especially of feces, makes small changes in weight entirely without significance. Accordingly, while the weights are given in our tables to the tenth of a kilogram, it must be recognized that differences of less than one-half kilogram are without consequence.

The statistics for Squad A are given in table 9, together with the normal weight for age and height as taken from the Medico-Actuarial Mortality Table (see column *a*). The initial weights of the squad are given in column *b*, and the difference between the normal and initial weights in column *c*. An examination of the initial weights for Squad A just prior to diet reduction as compared with the standard weights (see column *c*), shows that *Moy*, *Pec*, *Tom*, and *Fre*, were measurably under normal weight, although *Moy* was but 0.5 kg. below normal. *Tom*, who was slender and tall, of sedentary habits, and not given to athletic exercise of any kind, was 6.8 kg. less than the average weight for his age and height. *Pec*, who was a finely trained man, 44 years of age, and of a well-seasoned athletic type, was 2.2 kg. less than normal. *Fre* dropped out of the experiment in about two weeks, so there were actually but three men in the squad who were under normal weight. Special attention should be given to these three men in the discussion of the effects of the diet. A number of the men had a distinctly excess weight, six being 4 or more kg. above normal. *Can*, who showed the greatest difference, was the heaviest man in the squad. It is deemed of particular significance that these differences between normal or average body-weights and true weights are so great, with a reasonable proportion of the men varying either one way or the other from the standard. The influence of a restricted diet upon these two types of normal individuals should, therefore, be instructive.

The body-weight values for Squad B are collected in table 10, these including the normal weights for age and height (column *a*) as drawn

[1] Medico-Actuarial Mortality Investigation. The Association of Life Insurance Medical Directors and The Actuarial Society of America, New York, 1912, **1**, p. 38, table 4. This investigation gives data as to the expectancy of life according to height and weight (see vol. II) which are somewhat inaccessible to most readers, but which fortunately have been published by Dr. Joslin in his book (Joslin, Treatment of Diabetes Mellitus, 2d ed., Phila., 1917, p. 57).

[2] See technique used in weighing subjects, outlined on p. 75.

TABLE 9.—*Comparison of body-weights with normal standards, Squad A.*

Subject.	Age.	Height (Sept. 29, 1917).	(a) Normal weight for age and height.[1]	(b) Initial weight (Sept. 30, 1917).	(c) Difference between normal and initial weights (b-a).	(d) Minimum weight.	(e) Difference between normal and minimum weights (a-d).	(f) Greatest loss (b-d).	(g) Weight 20 per cent less than normal.	(h) Difference between minimum and 20 per cent limit (d-g).
	yrs.	cm.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.
Bro.....	26	167	60.3	61.8	+ 1.5	54.0	− 6.3	7.8	48.2	+ 5.8
Can.....	26	177	67.5	79.8	+12.3	68.8	+ 1.3	11.0	54.0	+14.8
Kon.....	20	[2]168	58.3	[3]69.0	+10.7	60.3	+ 2.0	8.7	46.6	+13.7
Gar.....	22	171	61.4	71.3	+ 9.9	62.3	+ 0.9	9.0	49.1	+13.2
Gul.....	24	166	59.2	66.8	+ 7.6	59.0	− 0.2	7.8	47.4	+11.6
Mon.....	32	171	64.7	68.8	+ 4.1	59.5	− 5.2	9.3	51.8	+ 7.7
Moy.....	23	174	64.0	63.5	− 0.5	56.0	− 8.0	7.5	51.2	+ 4.8
Pea.....	21	169	59.7	69.3	+ 9.6	60.0	+ 0.3	9.3	47.8	+12.2
Pec.....	44	170	66.5	64.3	− 2.2	57.8	− 8.7	6.5	53.2	+ 4.6
Spe.....	19	171	59.6	63.5	+ 3.9	55.3	− 4.3	8.2	47.7	+ 7.6
Tom.....	25	176	66.3	59.5	− 6.8	54.3	−12.0	5.2	53.0	+ 1.3
Vea.....	22	175	64.2	65.8	+ 1.6	58.3	− 5.9	7.5	51.4	+ 6.9
Fre.....	25	167	59.9	57.5	− 2.4	....	......	....	....	......

[1] Normal weight based on table 4 in report of the Medico-Actuarial Mortality Investigation, 1912, **1**, p. 38, deducting 8 lbs. for clothing.
[2] Height obtained Oct. 7, 1917.
[3] Weight obtained Oct. 28, 1917; weight on Oct. 7 was 67.3 kg.

TABLE 10.—*Comparison of body-weights with normal standards, Squad B.*

Subject.	Age.	Height (Oct. 7, 1917).	(a) Normal weight for age and height.	(b) Weight on Oct. 7, 1917.	(c) Difference between normal weight and weight on Oct. 7, 1917 (b-a).	(d) Weight on Jan. 6, 1918.	(e) Difference between normal weight and weight of Jan. 6, 1918. (d-a).	(f) Difference between weight on Oct. 7, 1917, and weight of Jan. 6, 1918. (d-b).	(g) Final or minimum weight with reduced diet (Jan. 28, 1918).	(h) Difference between normal weight and final or minimum weight (g-a).
	yrs.	cm.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.
Fis......	27	177	67.5	76.0	+8.5	76.3	+ 8.8	+0.3	71.7	+4.2
Har......	20	175	63.3	63.0	−0.3	63.7	+ 0.4	+0.7	59.1	−4.2
How.....	19	179	65.5	70.0	+4.5	72.0	+ 6.5	+2.0	66.2	+0.7
Ham.....	20	184	70.4	75.0	+4.6	74.8	+ 4.4	−0.2	69.9	−0.5
Kim......	25	[1]176	66.3	....	.....	61.9	− 4.4	.....	59.9	−6.4
Lon......	22	179	67.1	66.8	−0.3	[2]67.8	+ 0.7	+1.0	63.3	−3.8
Sch......	29	[1]166	60.5	....	.....	68.6	+ 8.1	.....	63.8	+3.3
Liv......	18	161	51.8	60.5	+8.7	63.6	+11.8	+3.1	58.6	+6.8
Sne......	22	175	64.2	72.3	+8.1	72.9	+ 8.7	+0.6	67.7	+3.5
Tho......	24	179	68.0	62.0	−6.0	63.2	− 4.8	+1.2	59.3	−8.7
Van......	24	179	68.0	67.3	−0.7	69.8	+ 1.8	+2.5	64.8	−3.2
Wil......	19	164	54.6	58.5	+3.9	59.8	+ 5.2	+1.3	56.9	+2.3

[1] Height obtained Jan. 5, 1918; age computed for date of Jan. 5, 1918, and not for Oct. 7, 1917, as with the other subjects.
[2] Weight obtained Dec. 16, 1917; Lon did not come to Boston with Squad B on Jan. 6, 1918.

from the Medico-Actuarial Mortality Investigation table, the actual weights on October 7, 1917, when the men first visited Boston, and again on January 6, 1918, just prior to the restriction in diet which began on January 8 (columns *b* and *d*). The differences between these records of actual weights and the normal weights for the age and height of the subjects are given in columns *c* and *e*. The individual members of Squad B changed slightly as the experiment progressed, *Kim* and *Sch* joining the group just prior to diet restriction; no body-weights for these two subjects are therefore given for October 7.

Comparing the differences between the weights on October 7 and January 6 for those who were weighed on the first date, we find that the tendency was for the entire squad to gain in weight during this period, the average for 10 men being 1.25 kg. (see column *f*). Only one man, *Ham*, showed a loss, but the difference was insignificant, being but 0.2 kg. The largest increase was that of *Liv* (3.1 kg.).

The tendency for the men to increase in weight during the first part of the academic year is in accordance with the opinion previously expressed by Professor Berry and others of the college faculty. This normal increase in weight is of special significance here, for it shows that the men in Squad B, when they began the reduced diet in January, were at a perceptibly higher level than if they had taken the low diet early in the fall. In other words, their body-reserves were considerably greater on January 6 than they were on October 7. Unfortunately, the character of these body-reserves is unknown to us. Whether the storage of nitrogen was greater, the difference in weight was chiefly fat, or there was a material increase in the glycogen storage can not be inferred from our data. This remains one of the important problems for future solution. The fact that the general picture exhibited by Squad B as to the total effect of a rapid reduction in diet and weight is essentially the same as that of Squad A is of unusual interest, viewed from the standpoint of normally existing larger body-reserves. But two men in Squad B were distinctly under normal weight on January 6, these being *Kim*, with a deficiency of 4.4 kg., and *Tho*, with a deficiency of 4.8 kg. (See column *e*.) *Lon* and *Har* were but little over normal weight. On the other hand, *Fis*, *How*, *Ham*, *Sch*, *Liv*, *Sne*, and *Wil* were all 4 or more kilograms overweight, the greatest excess weight being found with *Liv* (11.8 kg.).

NORMALITY OF MINIMUM BODY-WEIGHTS.

Finally, it is of interest to compare the body-weight of the men at the end of the reduction periods with the normal standards to find what proportion of the men after a prolonged reduction in diet would be classed as underweights according to the Medico-Actuarial Mortality Investigation standards. This comparison is also shown in tables 9 and 10. For this purpose the body-weights given for the subjects are

not necessarily those obtained at the end of the experiment, but the actual minimum weights recorded during the whole period of the observations. With Squad A these were found in the majority of instances about December 20, 1917; with Squad B the minimum weight was in every instance coincidental with the final weight taken on January 28.

When we compare the standard values with the minimum body-weights for the members of Squad A (see columns *a*, *d*, and *e* in table 9), we find that at their minimum weight 8 of these men were distinctly under normal weight, while only 2 were more than 1 kg. overweight (*Can* and *Kon*). The greatest differences found for these subjects are those between their initial and minimum weights; these differences are given in column *f*. The greatest loss on this basis is found with the heaviest man, *Can*, namely, 11 kg. The smallest loss was with one of the lighter men, *Tom*, this being only 5.2 kg.

With Squad B (see columns *a*, *g* and *h*, table 10), we find 6 of the men were still above normal weight after the period of greatly restricted diet, but the other 6 men had a weight below normal. The greatest difference was shown by *Tho*, who was 8.7 kg. under normal weight.

Since their loss in weight caused not a little anxiety on the part of parents and friends of these young men, who at times feared that the subjects were jeopardizing their health by too great a reduction in weight, the minimum weights of the men in Squad A are compared in table 9 with the acceptable weights for life insurance of men of similar age and height. It is the custom of a large number of life insurance companies to allow an underweight of 25 per cent on accepted risks, without special consideration on the part of the company. Other companies, more conservative, make an allowance of but 20 per cent. We have, therefore, computed for each of the men in Squad A the normal weight less 20 per cent for comparison with the minimum weight for these men. It is unnecessary to do this for the men in Squad B, since their weight reduction at no time approached the 20 per cent limit. From the figures in column *h*, table 9, it can be seen that no member of Squad A, including even *Tom*, who had the smallest initial weight, reached the limit which would cause his rejection by a life insurance company on the ground of underweight. When it is considered that the weight reduction for the whole squad averaged but 12 per cent, it is evident that in reality there were no grounds for apprehension, for even at this low weight the men were, on the basis of body-weight alone, eligible as risks with the best life insurance companies.

INDIVIDUAL BODY-WEIGHT CURVES.

The actual body-weights for these men under our standard conditions were obtained on numerous dates. It seems desirable to plot

them in the form of curves to show several important things, first, the loss in body-weight at the beginning of the experiment during the period of reduction in diet; second, the approximately constant level of body-weight during the period of partial realimentation; third, the not insignificant alterations in body-weight following the unavoidable, but regrettable, periods of unrestricted diet, *i. e.*, occasional Sundays, four days at the Thanksgiving season,[1] and 18 days at the Christmas recess; finally, the astonishing increase in body-weight incident to the complete withdrawal of all dietetic restrictions after February 4, 1918. Since this picture is so pronounced, it has been deemed advisable to plot an individual weight curve for each man in both Squad A and Squad B. In considering these curves, it should be remembered that the Thanksgiving recess was from November 29 to December 2, inclusive, and the Christmas recess from December 20 to January 6, inclusive, although some of the men did not return to college until later.

BODY-WEIGHT CURVES OF SQUAD A.

Body-weight curve of Bro (Fig. 57).

Prior to the reduction in diet, *Bro* had a weight of 61.8 kg. The next record of weight was not taken for about two weeks, during which time there had been a material curtailment of diet, but the weight had dropped to only 61 kg. Subsequently, owing to the restriction in diet,

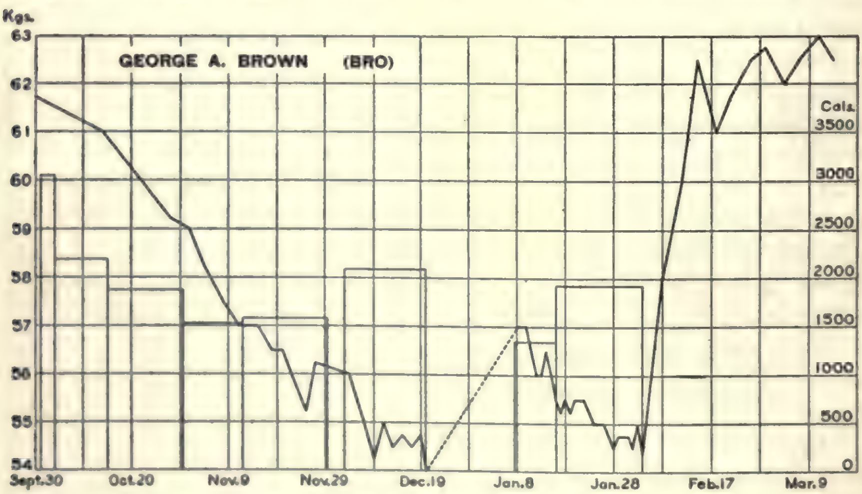

Fig. 57.—Body-weight curve of *Bro*.

the weight decreased in a reasonably regular manner until the unrestricted meal of November 25, after which there was a rise of approximately 1 kg. On December 9 the weight had fallen to a lower level

[1] The absence of a pronounced change in weight after Thanksgiving was doubtless due to the fact that records of the body-weight were not made until December 4, and the men had trained for a loss in weight to counterbalance the gain during the Thanksgiving recess.

than that shown on November 25 and stayed at an approximately constant level for two weeks. The minimum weight, 54 kg., was reached on December 20. During the 18 days of absence from college in the Christmas vacation, there was an increment of 3 kg., but the weight was brought down with reasonable rapidity by the subsequent curtailment of diet, and probably considerable exercise. *Bro* was then given a larger number of calories to hold him at the minimum weight-level observed during December. These calories apparently held the weight fairly constant, as there was a fluctuation of but 1 kg. in the last two weeks. The post-diet increase was immediate and enormous, for from the weight of 54.4 kg. on February 3 there was a sharp rise of 8 kg. in 11 days, which not only compensated for the entire loss during the experiment, but caused an increase of nearly 1 kg. over the initial weight. Thereafter, until the end of the observations on March 14 (a period of one month), the weight varied approximately 0.5 kg. from this higher level, with a distinct tendency for the body-weight to be somewhat higher than it was before the experiment.

Although this will be a subject for subsequent special discussion, attention should be called to the variation in the *net* calories[1] ingested, as indicated by the blocks on these curves. In the three days prior to the dietetic restriction, the net energy intake averaged 3,050 calories. There was then considerable curtailment, the calories falling at one time to nearly half the initial value. Approximately 1,950 calories were required to maintain this man at the lower weight level. No data are available regarding the calories ingested during the post-diet period.

Body-weight curve of Can (Fig. 58).

Can was the heaviest man in Squad A, his initial weight being 79.75 kg. Following the curtailment in diet there was a very marked and rapid loss in weight and, as is indicated by the increases in the net calories supplied, it became necessary to raise the energy intake perceptibly to hold the weight at the lower level. The first rise in the descending curve occurs shortly after the uncontrolled meal on November 11, but a decided rise of somewhat over a kilogram occurred after November 25, as was found with several other members of Squad A. This was followed by a somewhat rapid fall, the minimum weights being observed on December 15 and 20. This period of minimum weight-level was accompanied by a net calorie ingestion of approximately 2,475 calories.

During the Christmas vacation, as the broken line shows, there was an increase of somewhat over 4 kg. in weight. This was in part lost on the return to college, but as this subject had actually lost more than 10 per cent of his initial weight and seemed somewhat troubled by the fact, the caloric intake was adjusted to hold the body-weight

[1] See p. 271.

nearer a 10 per cent than a 12 per cent loss. It was found that 2,380 calories practically sufficed to hold the weight at this level. The post-diet increase in body-weight was striking, that is, from 69.3 kg. on

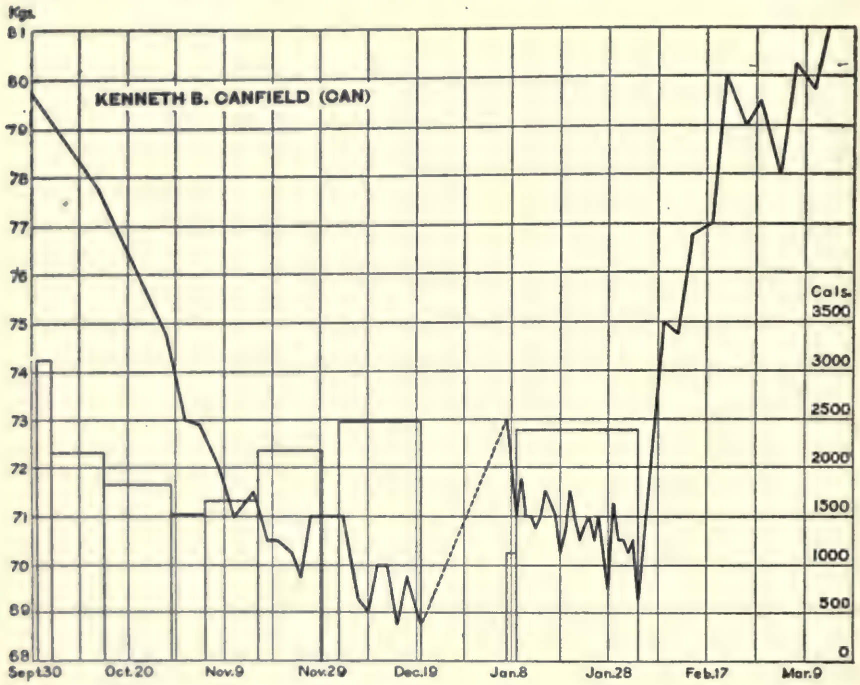

FIG. 58.—Body-weight curve of *Can*.

February 3 the body-weight rose with hardly a break to 80 kg. on February 21. This represents an increase of 10.7 kg. in less than three weeks. The tendency at the end of the observations was for the body-weight to be slightly higher than the initial weight, our last record for this man being 81 kg. or 1.25 kg. greater than the first record.

BODY-WEIGHT CURVE OF KON (FIG. 59).

From the statistical records for *Kon*, it will be observed that he did not begin the reduction in diet until some time after the other men in Squad A, as he was originally a member of Squad B. His body-weight as noted on October 7 was 67.25 kg.; during the next three weeks it rose to 69 kg., at which point he began the reduced diet. The basal energy values found for this man were unfortunately confined to only two days, but averaged at this time about 3,000 calories. He readily consented to the proposition to make a sharp reduction in the diet in the attempt to have him reach the 10 per cent lower weight-level about the same time as the other members of Squad A. Consequently he was given only a little over 1,500 calories, which, as the curve shows, caused a rapid fall in the body-weight.

The first break in the descending line is at November 15, *i. e.*, after the unrestricted meal on Sunday, November 11. This rise after a Sunday meal was also noted in the curves for *Bro* and *Can*. The irregular fluctuations in the next three weeks are somewhat difficult to interpret, for at this time the subject was on a very low diet. It was during this period that the trouble with his nose occurred. As may be noted from the subject's personal history (see p. 48), his nose was injured in a ball game on November 18. On November 30 he entered the hospital for an operation on the nose, when a piece of bone was removed. He was discharged from the hospital on the evening of December 1. As a matter of fact, the increments in the body-weight curve during the period of irregularity amount to a sum total of but 500 grams, which is probably not significant, and the general tendency is toward a lower level. A slight rise is evident after November 25,

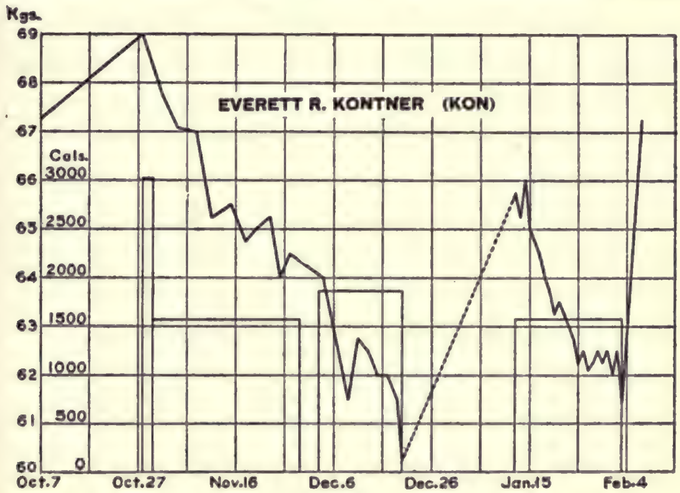

FIG. 59.—Body-weight curve of *Kon*.

when an unrestricted meal was again taken. Evidently this subject adhered rigidly to a low diet during the Thanksgiving recess, for when he returned to college his weight was somewhat lower than the weight recorded on November 25. A marked drop in weight followed, which was so rapid and so consistent that it was decided that the calories could be safely increased. During his absence from college for the Christmas holidays (December 20 to January 12), there was a large increase in his weight of somewhat over 5 kg. The diet was again somewhat reduced, and this reduction, combined with excessive exercise and hard work, produced a rapid and consistent change until the weight had fallen to a fairly constant level at somewhat above 62 kg. for the last 14 days of the experiment. Another operation on the nose was performed on January 22, when a second portion of bone was removed.

But one post-diet record of weight was obtained for this man, showing that in 4 days the body-weight increased nearly 6 kg. This rapid increase in body-weight must have been due in large part to an increase in the water content of the body, for an addition of 6 kg. of organized muscle or fat would have been impossible during this short time.

BODY-WEIGHT CURVE OF GAR (FIG. 60).

The weight for *Gar* prior to the restricted diet was 71.25 kg. With the reduced diet there was a consistent and steady fall in the curve until the first record after November 11, which showed the rise commonly found after the unrestricted Sunday meal. The weight then continued to fall and showed no increase during the Thanksgiving

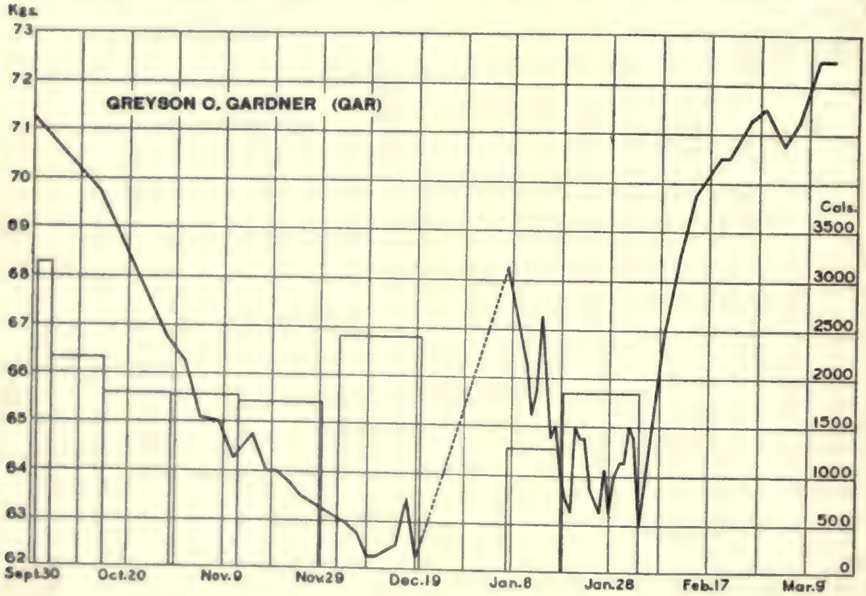

FIG. 60.—Body-weight curve of *Gar*.

recess. A great increment appeared when higher feeding was resumed. During the Christmas recess there was a gain of 5.8 kg. This was followed by a rather rapid fall incidental to an extremely low ingestion of food on the return to college, varied by one or two sharp rises. The last 15 days the weight fluctuated around 64 kg., which was evidently *Gar's* lower limit of weight. During the post-diet period there was the usual rapid rise in body-weight, with a total gain of 9.5 kg. When the measurements ceased, the subject was somewhat more than 1 kg. heavier than at the beginning of the observations.

BODY-WEIGHT CURVE OF GUL (FIG. 61).

The first part of the curve for *Gul* follows the same course as the other curves thus far examined. The slight rise after the unrestricted

meal on Sunday, November 11, is again noted; also an increase on November 23. The lower weight-level is evidently not far from 60 kg. In spite of the fact that the recorded weights for this subject show an increase of only 1 kg. during the Christmas vacation, it should be stated that, according to the report of the subject, very large increases and decreases in weight were observed during this time. The subject reported one increase of 5.9 kg., which necessitated a rapid reduction by exercise and purgatives. On returning to college, he voluntarily took a very low diet of approximately 1,000 calories, but

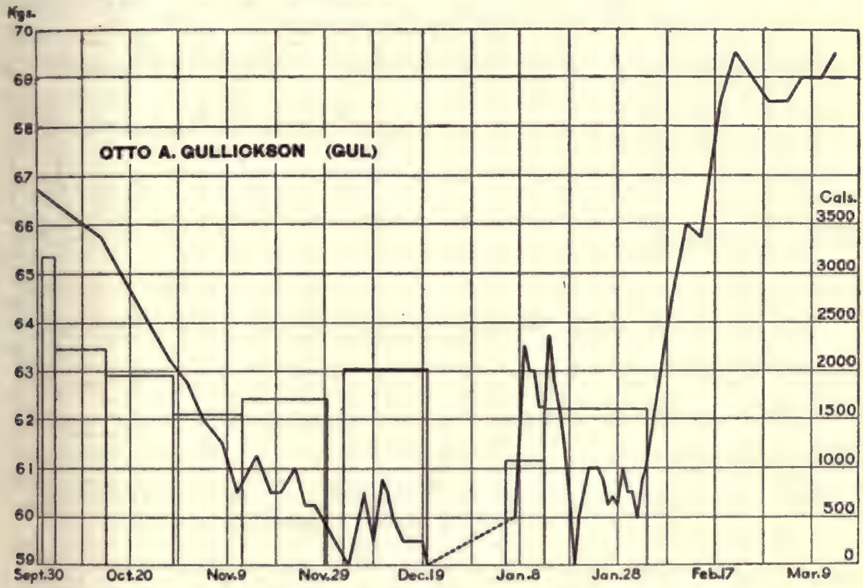

FIG. 61.—Body-weight curve of *Gul.*

even under these conditions there was an increase in weight, probably due to an increase in the water content of the body. During the final two or three weeks the body-weight fluctuated either side of 60.5 kg., which is not far from his minimum value. At the conclusion of the experiment the usual rapid rise in body-weight was observed, until the subject had reached a level nearly 3 kg. higher than the initial weight in September. This subject was noted among his colleagues as a heavy eater. His potentialities for consuming large quantities of food are indicated by the typical day's record selected from his report of unrestricted diet, which shows the large number of calories usually taken on the free days. (See table 33, p. 269.)

BODY-WEIGHT CURVE OF MON (FIG. 62).

Perhaps no subject in the whole squad adhered so rigidly to dietetic control as did *Mon.* He was a wrestler, and was rather anxious to secure a lower weight so that he might enter a lower wrestling class

than the one in which he had formerly been. Consequently we find a rather consistent fall in the entire curve, with an almost inappreciable increase after November 11, no change throughout the Thanksgiving vacation, and a small rise during the Christmas holidays; the body-weight found a level thereafter, which was not far from 61 kg. It is evident, however, that at the conclusion of the test *Mon* decided to

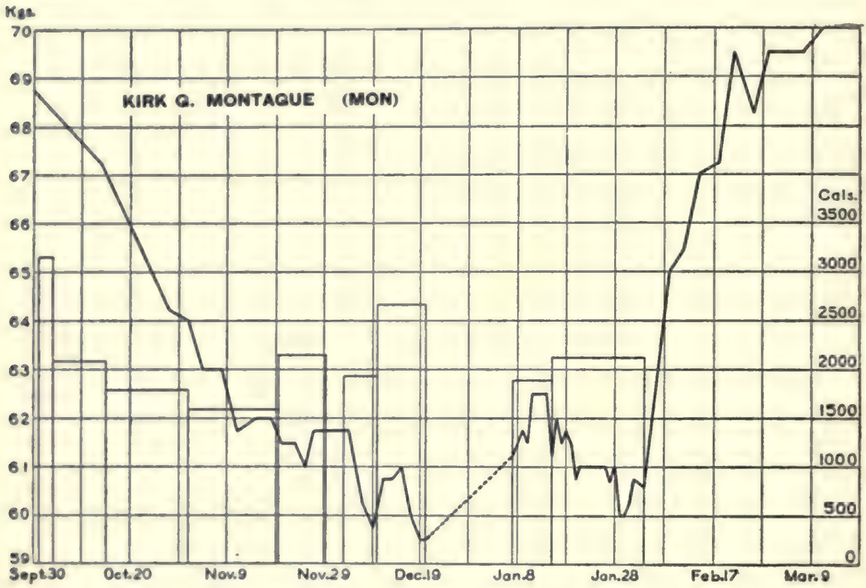

FIG. 62.—Body-weight curve of *Mon*.

resume his original weight, for we have a marked post-diet increase which brought the weight not only to the initial level, but nearly 1.5 kg. above it.

BODY-WEIGHT CURVE OF MOY (FIG. 63).

From an initial weight of 63.5 kg., the weight of *Moy* fell rather slowly in comparison with the other curves. It was found that the diet was somewhat too large for a rapid reduction. The calories were therefore restricted still further three successive times, this restriction finally bringing *Moy's* weight just before Thanksgiving to a level of 58 kg. With this subject, also, there was an increase after the unrestricted meal of Sunday, November 11. In the month of December his weight remained constant at not far from 57 kg.; there was then a pronounced increase of 4.5 kg. during the Christmas holidays. When he returned to college a severe reduction was made in the diet, which was followed by a rapid loss in weight, although with considerable fluctuation. During the last two weeks of the experiment the body-weight fluctuated around 58 kg. The post-diet rise is especially interesting as showing an enormous increase, which is rela-

tively the largest increase that occurred in the whole series of observations of body-weight, *i. e.*, 21.2 per cent of his weight on February 3. This subject gained 12.25 kg. in slightly over a month. It is worthy of note that this is one of the subjects who was slightly under the normal weight at the beginning of the experiment. When the records for this

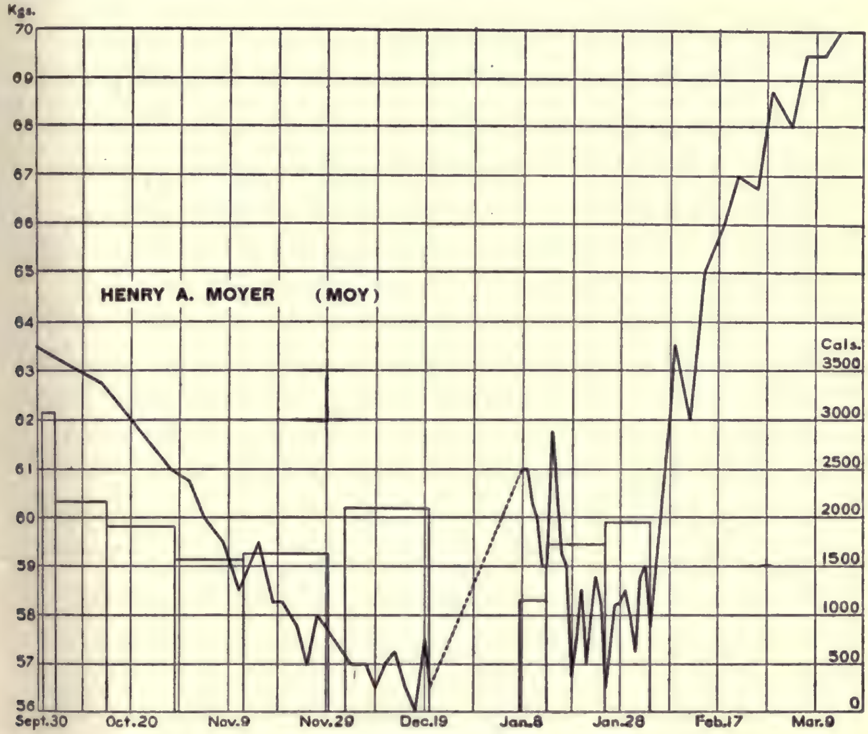

FIG. 63.—Body-weight curve of *Moy*.

subject ceased on March 14, that is, approximately six weeks after the end of the diet experiment, he weighed 6.5 kg. more than at the beginning of the observation in September.

BODY-WEIGHT CURVE OF PEA (FIG. 64).

Pea was distinctly of an athletic temperament and build, exercised a great deal, and lost weight rapidly on a restricted diet, falling from his initial weight of 69.25 kg. to 61.25 kg. on November 11. The first upward break in the curve occurred immediately thereafter in common with most of the subjects after the unrestricted meals on the Sundays in Boston. Until December 20 the body-weight fluctuated about this point, which was evidently a basal minimum. In the Christmas recess there was an increase of 6 kg., followed by a rapid fall on a very much restricted diet, with a fluctuating but slower fall thereafter to the end of the experiment. In the last week the body-weight

remained constant at approximately 61.5 kg. With the resumption of free diet a very large increase in body-weight occurred. From February 3 to March 14 this subject gained in weight 12.7 kg., the record for the last date being actually 4.75 kg. greater than at the beginning of the experiment in September.

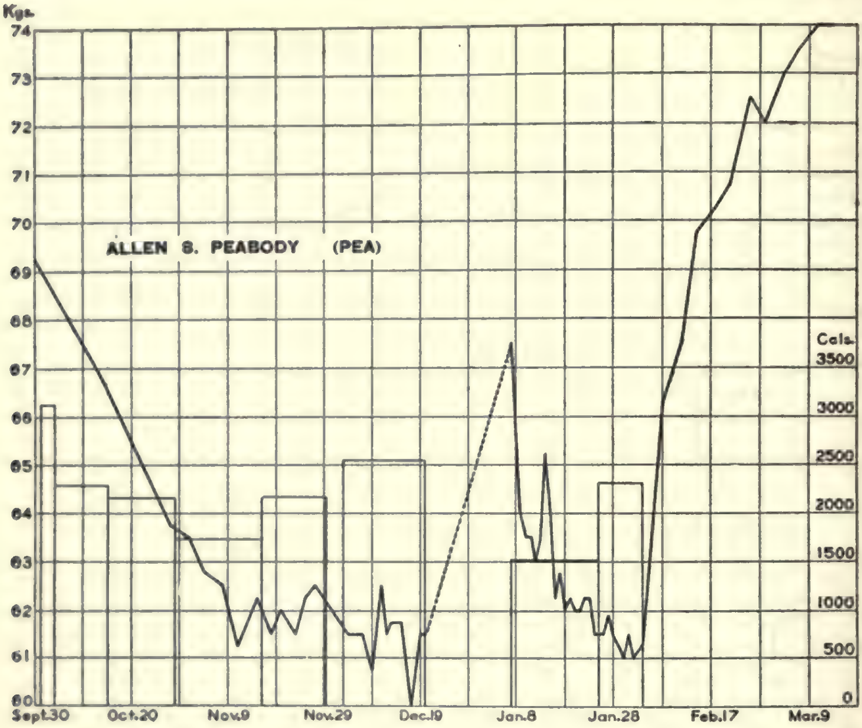

FIG. 64.—Body-weight curve of *Pea*.

BODY-WEIGHT CURVE OF PEC (FIG. 65).

Pec was one of the subjects who was definitely under the normal weight at the beginning of the experiment. He was an unusually well-trained man, 44 years of age, and found great difficulty in losing weight. Even on a very restricted diet the weight curve did not fall so rapidly as one would expect. When at home, and also on a free Sunday, he found difficulty in limiting the amount eaten, as may be noted subsequent to November 11, when there was the usual gain of weight following a free day. Under strict training, however, he lowered his body-weight until he finally reached a minimum of 57.75 kg. on December 9. Throughout the month of December the weight was not far from 58.5 kg. at this lower level. A small increase was noted at the end of the Christmas recess, although, as the subject was for a week of this time on volunteer Y. M. C. A. duty at Camp Devens, he reported

on unrestricted diet a material increase in weight which was rapidly removed by severe training just prior to returning to college. During the last two or three weeks of the experiment the body-weight fluctuated somewhat above or below 59 kg. In the last week it had a tendency to be slightly below 59 kg. Owing to the great earnestness of this man, and the fact that the dietetic restrictions seemed to cause him considerable anxiety, it was necessary to be cautious about reducing the weight rapidly or to a great extent. It was finally

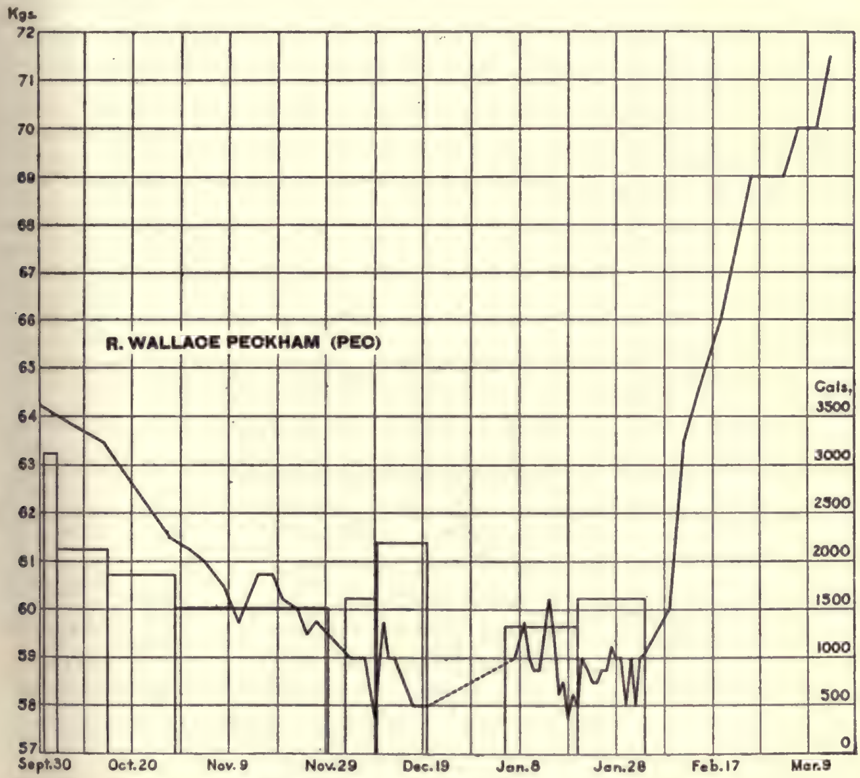

FIG. 65.—Body-weight curve of *Pec.*

decided that no attempt would be made to have him lose the 10 per cent expected of the other subjects. Greatly to his satisfaction, however, he succeeded in reaching the 10 per cent lower level, but he was not allowed to go below this weight. His earnestness of purpose and desire to hold his lower weight-limit are seen by the small number of calories that he consented to live upon during the last few weeks of the experiment. The usual rapid post-diet rise was observed for this subject, also. Between February 3 and March 14 there was an increase of somewhat over 12 kg., the final weight being more than 7 kg. above the initial weight in September.

BODY-WEIGHT CURVE OF SPE (FIG. 66).

Although *Spe* could not complete the experiment, owing to an unforeseen and unfortunate illness which necessitated the observations being stopped on December 13, his body-weight curve indicates a consistent regular loss until November 11, when there was the usual

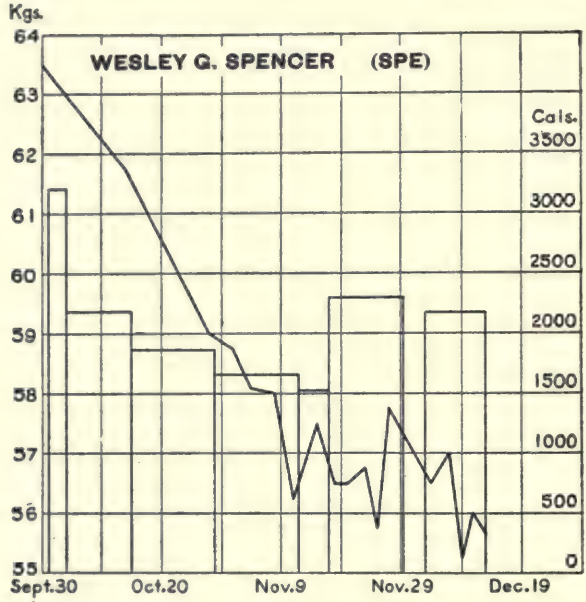

FIG. 66.—Body-weight curve of *Spe*.

noticeable rise. There was also a rise after the unrestricted meal on November 25, with a tendency for the weight to remain at the lower level of approximately 56 kg. during the period between November 11 and December 13. To hold him at this weight it was necessary to increase the calories to approximately 2,250 calories.

BODY-WEIGHT CURVE OF TOM (FIG. 67).

One of the most sedentary men in the whole squad was *Tom*, who was under normal weight at the beginning of the experiment. His duties in the college store prevented his taking a large amount of exercise and he found great difficulty in reducing his weight on the diet supplied to the other men. Consequently the fall in the body-weight curve is much slower than with the other subjects. There is, however, the characteristic rise after November 11 and another after November 25, both of these after the unrestricted diet on the Sundays following the Boston experiments. Subsequently, however, until the beginning of the Christmas recess, his body-weight remained essentially constant at about 55.5 kg. During the Christmas recess he was at home and was operated upon for hemorrhoids. He thus underwent

hospital treatment with hospital dietetic régime. The day after he returned to college, *i. e.*, on January 12, his body-weight was 1.25 kg. above the record on December 20. With continued low diet the weight fell to a point averaging not far from 55 kg. during the last two weeks of the experiment. The post-diet rise was by no means so striking or so

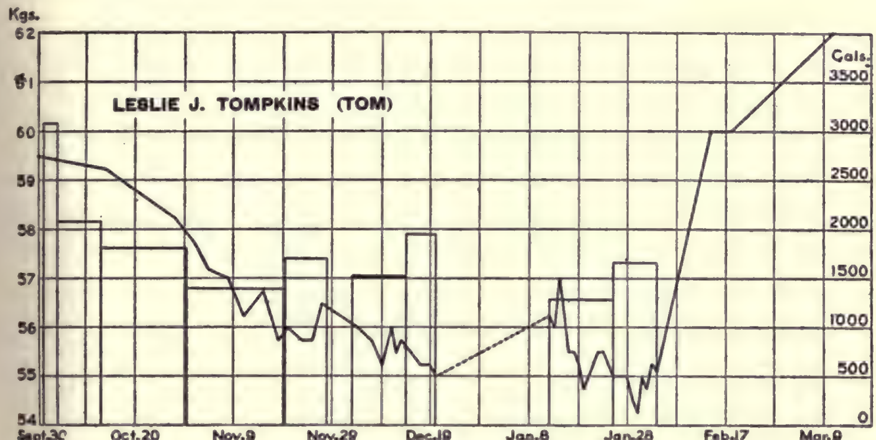

FIG. 67.—Body-weight curve of *Tom*.

extended as that for the other men, although he increased to somewhat over his initial level in about 10 days. The last weight recorded in the diet experiment was 55.1 kg. The first weight for the post-diet period, that of February 14, was 60 kg.; the last weight (March 11) was 62 kg., a weight 2.5 kg. greater than the initial weight for this man.

BODY-WEIGHT CURVE OF VEA (FIG. 68).

Vea, like *Tom*, was not so athletic as the other subjects, and found it somewhat difficult to reduce his weight on the number of calories given. The body-weight curve, however, runs a regular downward course, with the usual rise after the two unrestricted Sundays, November 11 and November 25. During the month of December the body-weight was about 59.5 kg. Although there was some increase in weight during the Christmas recess, *Vea* was able to reduce his weight by severe training, and came back to college with a body-weight only 0.75 kg. greater than when he left Springfield on December 20. From January 7 until February 3 the body-weight fluctuated about a point a little less than 59 kg. The initial post-diet rise was very pronounced. On February 3 (the end of the diet period) his weight was 58.5 kg.; on March 14, the last record obtained with him, the body-weight was 69.25 kg. After the diet period ended, therefore, this subject gained in weight nearly 11 kg. in less than six weeks, the final weight being, as a matter of fact, 3.5 kg. greater than the initial weight in September.

EFFECT OF UNRESTRICTED MEALS.

One of the most perplexing factors in the whole research was the unrestricted meals allowed Squad A, *i. e.*, those taken Sunday noon after the biweekly experiment in Boston, and the diet during the Thanksgiving and Christmas recesses. The academic program made it possible for many of these men to go to their homes every two weeks. Under these conditions they would take their meals at the family table and, on account of the apprehension of parents and friends, it was almost obligatory for the men to eat more food than was commonly served at the diet table. After considerable discussion it was deemed absolutely essential to allow these men unrestricted diet on these days, but they were especially cautioned to curtail so far as possible the consumption of protein. The men consented to report in writing to the best of their knowledge the food eaten in the unrestricted meals

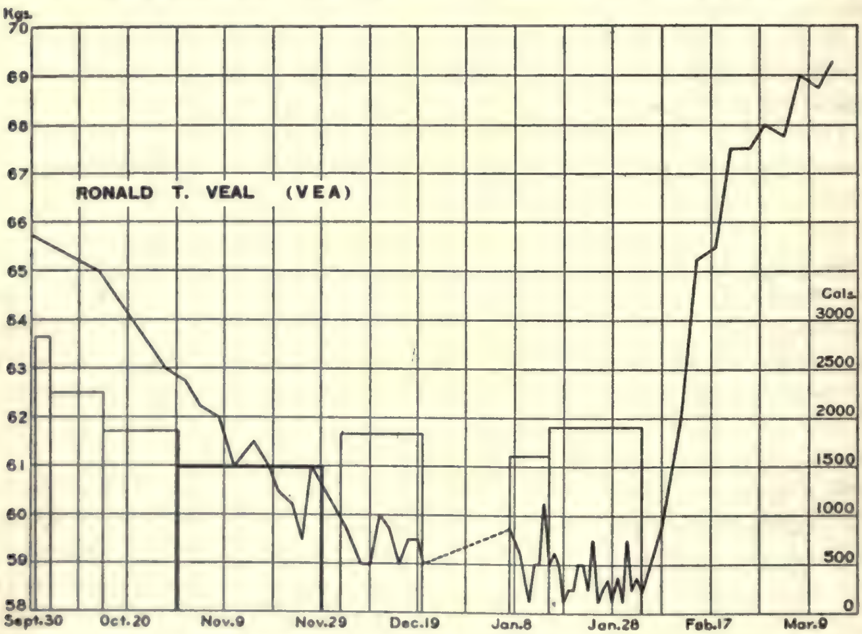

FIG. 68.—Body-weight curve of *Vea.*

on the alternate Sunday noons. It will be recalled that they were given a standardized laboratory breakfast and the Sunday evening meal was usually very light; hence, the chief extra energy was obtained in the Sunday noon dinner.

With nearly every man there was a perceptible increase in the body-weight following the free meal, this increase frequently amounting to as much as 1 kg. In the curves for all of the subjects but *Bro*, the first actual rise occurs shortly after the unrestricted day November 11–12. We thus have a definite rise in weight, which can be ascribed solely to

the excess food eaten on this unrestricted day. With 10 subjects this rise is also shown after November 25, and with many of the subjects to an even greater degree. The increase in weight after November 25 represents for five of the subjects the second appreciable increase in the weight curve. If one disregards the slight increase with *Tom* of 250 grams between the fortieth and fifty-fifth days, his curve likewise shows the second noticeable increase in the period following November 25.

The increase in weight shown after the Sunday meal is still more evident in the weights recorded after the Christmas vacation during which the diet was unrestricted for a considerable period. In spite of the utmost care on the part of the experimenters, the emphasis laid upon the importance of retaining, so far as possible, the original body-weight and the definitely expressed hope that the men would return at or near the body-weight at which they left Springfield, practically all the men came back to college after the Christmas recess with a very much larger body-weight. Certain members of the diet squad carried out the dietetic restrictions during the period of absence, holding their weight at essentially a constant level; these men are especially to be commended. In regard to the other men, it should be stated that it was expressly stipulated that if they continued as subjects after Christmas they should be allowed to go home for the holidays without restriction as to diet, the only condition being that they should, so far as possible, curtail the protein and fat intake. This caution to reduce the protein and fat, even when on unrestricted diet, was not disliked by the men, who had craved carbohydrate food particularly throughout the entire experiment. Hence we find an excessive consumption of cakes, candies, pies, and other sweets in the record of food eaten during the Christmas recess.

An examination of the nitrogen in the food (see table 34, p. 270) shows that, in spite of the injunctions given them, the subjects consumed not a little nitrogen in the unrestricted meals, which at times reached an excessive amount, and unquestionably led to nitrogen storage. An examination of the nitrogen excretion on the Mondays following these days of excess food shows that usually, when there was a reasonably regular loss of nitrogen prior to the Sunday meal, this loss either ceased, and became a slight positive gain, or was very much decreased. Unfortunately, the absence of a record of the urine for these Sundays makes the whole question of nitrogen balance somewhat uncertain.

SPECIAL FACTORS INFLUENCING CHANGES IN BODY-WEIGHT.

Following the initial period of loss in weight resulting from the material curtailment of diet, there was with all of the men in Squad A more or less variation above or below the lower weight-level. These fluctuations can be explained in several ways: First, they may

have been due to actual loss of tissue on account of continued undernourishment, with subsequent additions to the body-tissue as a result of extra feeding; second, they may have been due, in part at least, to variations in the amount of feces passed at different times. This applies especially to one of the subjects (*Pec*), whose habits of defecation were unique in our experience. With this subject periods of 5 or 6 days frequently passed without defecation, while at times very large quantities of feces were excreted. Finally, in spite of our precautions to secure an empty bladder and minimum drinking of water for each subject before weighing, considerable urine may have been retained. But probably the largest factor influencing the body-weight was the storage of water. It was for this reason that we insisted upon relatively long periods of constancy in weight before attaching any special significance to the measurements obtained.

Fortunately, the influence of the storage of water upon the changes in body-weight gives us a good suggestion as to the character of the gains in weight following the Christmas recess. Were these gains in weight due to actual body-tissue, particularly fat, it would require very considerable dietetic restriction and great muscular activity to reduce the excess weight. It is commonly assumed that it would be extremely difficult for a man to utilize 9,000 calories in one day. A man at very severe muscular work is supposed to require approximately 6,000 calories. While these men exercised considerably after the Christmas vacation, and much more than normally, their muscular activity was in no wise comparable to the severe work of a Canadian lumberman, and it is doubtful if their total metabolism could have reached much more than 4,000 or 4,500 calories per day during this short period of excessive exercise. On this basis it would require two days of pure fat combustion to remove 1 kg. of fat from the body. As the charts show, however, the loss in weight with all the subjects was very rapid after the return from the Christmas vacation; hence we believe that the increases in weight were more apparent than real in that they were due in large part to the storage of water rather than to the addition of organized tissue. This seems the more probable inasmuch as the diet commonly consumed when the subjects were free from restriction contained an excess amount of carbohydrate, which would tend to promote the retention of water in the body. This experience reminds us strongly of the error Grafe[1] was led into in assuming that a return to weight of a previously starved dog indicated complete replenishment of lost tissue.

During the Christmas recess the men reported maximum gains in weight which were, in some cases, not far from 5 or 6 kg. *Pea* reported a gain of about 9 kg. Subject *Tom* was operated upon for hemorrhoids during the Christmas recess; accordingly his gain was barely 1 kg. Most of the men underwent strict training in the last few days

[1] See page 25 of this monograph.

of the vacation to reduce their weight, and several (*Mon, Pec,* and *Gul*) abstained from food entirely on January 5 and 6. It must be remembered, therefore, that the weights recorded in the curves for January 7 by no means represent the maximum increase during the Christmas recess as a result of the freedom from the restricted diet.

BODY-WEIGHT CURVES OF SQUAD B.

From the data already given in table 10 it can be seen that most of the men in Squad B had a tendency to increase in weight during the academic year. These increases are shown in the body-weight curves for the men in Squad B (figs. 69 to 73). With *Har, Fis, Sne,* and *Lon* there was considerable fluctuation in the weight prior to the dietetic restriction, but in general the body-weight tended to increase. The extreme regularity of the curve following the dietetic restriction is, however, strikingly significant. These men were all given a diet containing approximately 1,400 net calories. The resultant fall in body-weight is markedly uniform and to such a degree that the curves might almost be superimposed in many instances. When one considers that we deal here with men of varying initial weights and varying activities, this uniformity is indeed surprising. An exception to this uniform fall in weight is shown by the curve for *Kim,* whose loss in weight was less than that for any of the other men in Squad B. *Kim* was, however, one of the men who was most deficient

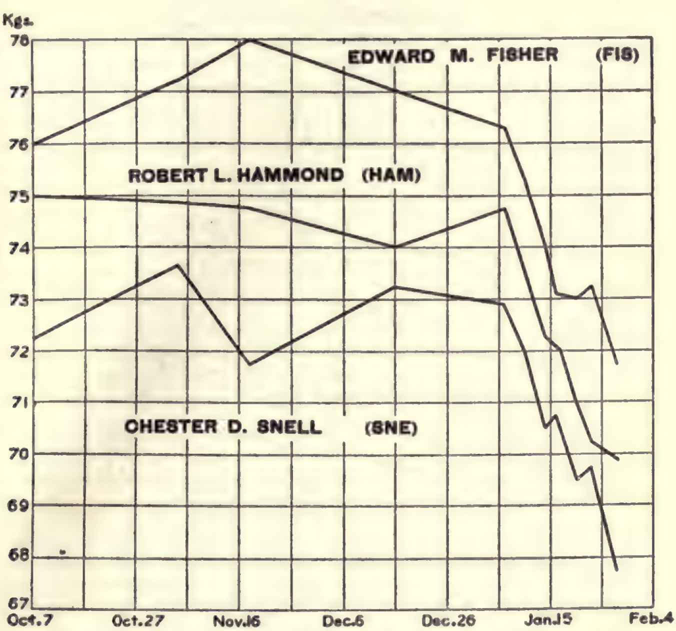

FIG. 69.—Body-weight curves of *Fis, Ham,* and *Sne.*

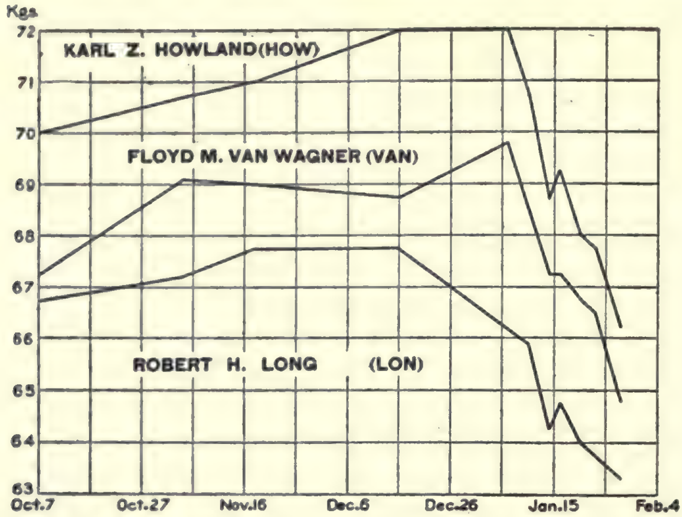

FIG. 70.—Body-weight curves of *How*, *Van*, and *Lon*.

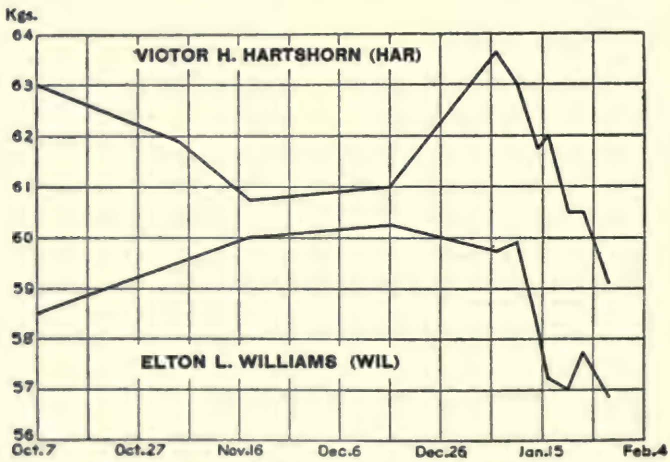

FIG. 71.—Body-weight curves of *Har* and *Wil*.

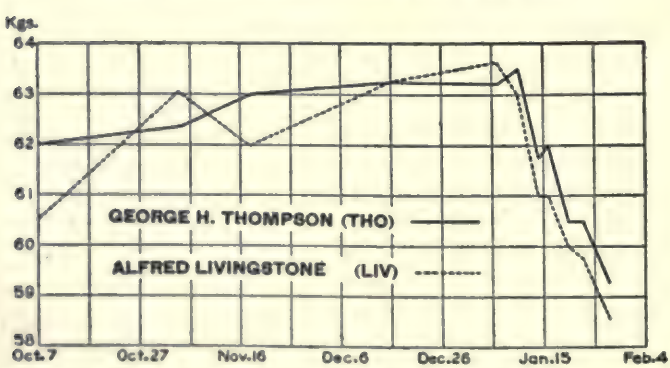

FIG. 72.—Body-weight curves of *Tho* and *Liv*.

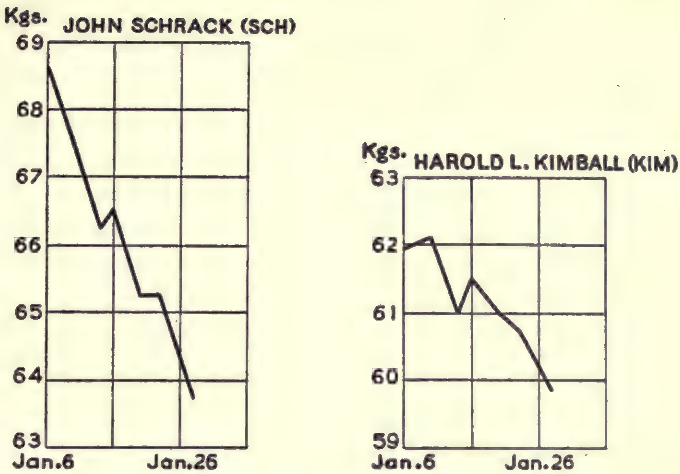

FIG. 73.—Body-weight curves of *Sch* and *Kim*.

in body-weight at the start, being 4.4 kg. below normal weight. On the other hand, the curve for *Tho*, who was even more deficient in weight, shows a very rapid fall as a result of the restriction in diet.

LOSSES IN BODY-WEIGHT DUE TO RESTRICTION IN DIET.

The losses in body-weight of Squads A and B are recorded in table 11. In interpreting this table it should be recalled that Squad B was subsisting upon a uniform diet of approximately 1,400 net calories, *i. e.*, all the men received practically the same amount, while the diet for the members of Squad A varied. The absolute losses for the men are not, however, so significant as the percentage losses, and these are also given for both squads in table 11.

For Squad A two low values have been calculated: First, the absolute minimum for the entire period of observation, and second, the weight observed at the conclusion of the experiment. The greatest loss experienced with Squad A is recorded in column *d*, in kilograms, and the percentage loss, as compared with the initial weight, in column *e*. The values in column *d* were given in table 9, and have already been discussed in that connection. The greatest percentage loss was that found for *Can* of 13.8 per cent, although two others (*Mon* and *Pea*) showed a percentage loss of 13.5 and 13.4 per cent, respectively. The smallest loss was that found for *Tom* of 8.7 per cent. The average maximum loss for the entire squad was 12.1 per cent.

When we examine the final weights for Squad A, we find that none of the men retained their maximum loss at the end of the experiment, but that all increased in weight slightly, although the increase for *Vea* was only 0.2 kg. The greatest loss at the end of the test was still shown by *Can*, with a percentage loss of 13.2 per cent. The mini-

TABLE 11.—*Percentage losses in body-weight of Squads A and B.*

Squad A.							
Subject.	(*a*) Initial weight (Sept. 30, 1917).	(*b*) Minimum weight during reduced diet.	(*c*) Final weight with reduced diet (Feb. 3, 1918).	Loss in weight. Greatest loss (*a-b*). (*d*) Amt.	Greatest loss (*a-b*). (*e*) Per cent.	Final loss (*a-c*). (*f*) Amt.	Final loss (*a-c*). (*g*) Per cent.
	kg.	*kg.*	*kg.*	*kg.*		*kg.*	
Bro	61.8	54.0	54.4	7.8	12.6	7.4	12.0
Can	79.8	68.8	69.3	11.0	13.8	10.5	13.2
Kon	[1]69.0	60.3	61.5	8.7	12.6	7.5	10.9
Gar	71.3	62.3	63.0	9.0	12.6	8.3	11.6
Gul	66.8	59.0	61.0	7.8	11.7	5.8	8.7
Mon	68.8	59.5	60.6	9.3	13.5	8.2	11.9
Moy	63.5	56.0	57.8	7.5	11.8	5.7	9.0
Pea	69.3	60.0	61.3	9.3	13.4	8.0	11.5
Pec	64.3	57.8	59.1	6.5	10.1	5.2	8.1
Spe	63.5	55.3	[3]55.7	8.2	12.9	.....	.....
Tom	59.5	54.3	55.1	5.2	8.7	4.4	7.4
Vea	65.8	58.3	58.5	7.5	11.4	7.3	11.1
Av.	67.0	58.8	59.8	8.2	12.1	7.1	10.5

Squad B.				
Subject.	(*h*) Initial weight (Jan. 6, 1918).	(*i*) Final weight with reduced diet (Jan. 28, 1918).	Loss in weight (*h-i*). (*j*) Amt.	Loss in weight (*h-i*). (*k*) Per cent.
	kg.	*kg.*	*kg.*	
Fis	76.3	71.7	4.6	6.0
Har	63.7	59.1	4.6	7.2
How	72.0	66.2	5.8	8.1
Ham	74.8	69.9	4.9	6.6
Kim	61.9	59.9	2.0	3.2
Lon	[2]67.8	63.3	4.5	6.6
Sch	68.6	63.8	4.8	7.0
Liv	63.6	58.6	5.0	7.9
Sne	72.9	67.7	5.2	7.1
Tho	63.2	59.3	3.9	6.2
Van	69.8	64.8	5.0	7.2
Wil	59.8	56.9	2.9	4.8
Av.	67.9	63.4	4.4	6.5

[1] Weight obtained Oct. 28, 1917; weight on Oct. 7 was 67.3 kg.
[2] Weight obtained Dec. 16, 1917; *Lon* did not come to Boston with Squad B on Jan. 6, 1918.
[3] Weight obtained on Dec. 13 just before subject left the squad.

mum loss was again found with *Tom*, with a percentage loss of 7.4 per cent. The average loss for the entire squad was 10.5 per cent. This is of special interest, as it will be recalled that the effort was made to secure an average loss in weight for these men of 10 per cent, and all of the men, except *Tom*, were able to reduce their weight to this extent. *Pec* found this reduction difficult, but was finally able to exceed the 10 per cent limit slightly. Thereafter he was given a little more freedom in diet, with a consequent increase in weight, so that the loss at the end of the experiment was but 8.1 per cent.

The diet experiment with Squad B continued for but three weeks. The loss recorded at the end of the period ranged from a minimum of 2 kg. with *Kim* to a maximum of 5.8 kg. with *How*. Aside from the low values found with *Kim* and *Wil*, there is a striking uniformity in the losses of the members of this squad. The percentage losses show this general uniformity clearly. If we exclude the percentage losses for *Wil* of 4.8 per cent and *Kim* of 3.2 per cent, the range is from *How*, 8.1 per cent, to *Fis*, 6.0 per cent, with a general average loss of 6.5 per cent.

POST-DIET INCREASES IN BODY-WEIGHT OF SQUAD A.

Although numerous experiments could be made upon a squad of men at the lower nutritional level and during the recuperation period, it was impracticable to make further observations, since a number of

the men left college and other duties prevented most of the remaining subjects from volunteering. Furthermore, the members of the Laboratory staff were fully occupied in completing the tabulations and analyses of the material in the major research. We have, therefore, only the records of the normal increments in body-weight in the subsequent period of recuperation. The balance used during the diet experiment, which had been carefully calibrated by the Nutrition Laboratory, remained at Springfield for several months after the research was completed. The men were requested to weigh themselves upon the balance from time to time during the spring. The usual normal conditions were observed, namely, the weighings were made with the subject in a post-absorptive condition, immediately after passing urine, nude, and the first thing in the morning. We were particularly fortunate in having the cooperation of one of the subjects, Mr. Ronald T. Veal, who personally superintended these post-diet weighings.

In the discussion of the individual body-weight curves, attention has already been called to the enormous gains in weight of practically every member of the squad after the experiment was concluded. These increments have been collected in table 12, together with the initial

TABLE 12.—*Increase in body-weight after resumption of normal diet, Squad A.*

Subject.	Initial weight (Sept. 30, 1917).	Minimum weight during reduced diet.	Final weight with reduced diet (Feb. 3, 1918).	Post-experimental weight (Mar. 14, 1918).	Increase in weight on March 14.		
					Above weight of Feb. 3, 1918.	Above minimum weight.	Above initial weight.
	kg.	*kg.*	*kg.*	*kg.*	*kg.*	*kg.*	*kg.*
Bro......	61.8	54.0	54.4	62.5	8.1	8.5	0.7
Can......	79.8	68.8	69.3	81.0	11.7	12.2	1.2
Kon.....	[1]69.0	60.3	61.5	[2]67.3	[2]5.8	[2]7.0	−[2]1.7
Gar......	71.3	62.3	63.0	72.5	9.5	10.2	1.2
Gul......	66.8	59.0	61.0	69.5	8.5	10.5	2.7
Mon.....	68.8	59.5	60.6	[3]70.0	[3]9.4	[3]10.5	[3]1.2
Moy.....	63.5	56.0	57.8	70.0	12.2	14.0	6.5
Pea......	69.3	60.0	61.3	74.0	12.7	14.0	4.7
Pec......	64.3	57.8	59.1	71.5	12.4	13.7	7.2
Tom.....	59.5	54.3	55.1	[3]62.0	[3]6.9	[3]7.7	[3]2.5
Vea......	65.8	58.3	58.5	69.3	10.8	11.0	3.5

[1] Weight for Kon obtained Oct. 28, 1917.
[2] Post-experimental weight for Kon was obtained Feb. 7, 1918.
[3] Post-experimental weights for Mon and Tom were obtained Mar. 11, 1918.

weights, the minimum weights during the period of reduced diet, the weights at the end of the period of reduced diet (February 3), and the last weights plotted on the charts (March 14). In the last three columns of the table are given, respectively, the increases on March 14 above the weights of February 3, the increases above the minimum weights, and the actual increases above the initial weights in the fall.

The period between February 3 and March 14 represents 5½ weeks (39 days). During this time these subjects gained from a minimum of 5.8 kg., in the case of *Kon*, to a maximum of 12.7 kg., in the case of *Pea*, the average gain in weight of the 11 men being 9.8 kg. The gain in weight over the lowest weight observed in the experiment ranged from 7.0 kg. with *Kon*, obtained February 7, *i. e.*, 4 days after the removal of the diet restrictions, to 14.0 kg. with *Moy* and *Pea*, with an average gain of 10.8 kg. What is of prime importance, however, is the fact that with every man but *Kon*, whose last weight was February 7, the initial weight, as found in September, 1917, was exceeded on March 14. This increase ranged from 0.7 kg. with *Bro* to 7.2 kg. with *Pec*. Increases of 2.5 or more kilograms were observed for 6 of the 11 subjects.[1]

This great increase in weight following a period of reduced diet recalls previously reported observations on a group of 5 college students who were subjected to a 2-day fast at Wesleyan University in the fall of 1905.[2] By January, 1906, all of the men had made measurable gains over their initial weight. A rough comparison with the body-weights of a number of college students during the same period of the year shows that while they also had a general tendency to increase in weight during this portion of the year, the increase for the subjects of the short fasting experiments was noticeably more than that for their fellow students. The suggestion was made at that time that a short period of inanition may so stimulate anabolism as to cause a subsequent increase in body-weight in possible preparation for further drafts upon body-tissue. "The tendency to store body-fat exhibited by the subjects of short fasts may indicate a protective action on the part of the body to provide for a subsequent draft upon body-material."[3]

BODY-WEIGHTS COMPARED TO MORTALITY STANDARDS.

A further analysis may be made of the body-weights of these men to find if they represent optimum weights or not. For this purpose we may compare them with the normal averages given in the Medico-Actuarial Mortality Investigation tables for corresponding ages and heights, and note the expectancy of life as there established.[4] Although the desirability of underweight has been especially emphasized by a number of writers,[5] more particularly in Dr. E. P. Joslin's admirable treatise on diabetes mellitus,[6] and in connection with the general problem of overeating, it is surprising that as a rule little stress is laid upon the fact that it is distinctly disadvantageous for young people to be underweight, although distinctly advantageous for people over 35 to be

[1] A portion of this gain may logically be attributed to the normal tendency of college students to gain during the fall and winter.

[2] Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 526.

[3] Benedict, Harvey Society Lectures, 1906–1907, p. 199. Lecture delivered January 12, 1907.

[4] Medico-Actuarial Mortality Investigation, II. Influence of Build on Mortality. The Association of Life Insurance Medical Directors and the Actuarial Society of America, New York, 1913.

[5] Welch, Trans. Actuarial Society of America, 1916, **17**, p. 17.

[6] Joslin, Diabetes Mellitus, Philadelphia, 1917, 2d ed., p. 56.

underweight. Thus, with young people between 20 and 24 years of age the mortality for the average weight is exceeded in all cases with an underweight of 5 or more pounds. From a careful analysis of the Medico-Actuarial Mortality Investigation records, which was made available through the kind assistance of Mr. Arthur Hunter, the actuary of the New York Life Insurance Company, it has been shown that this striking difference between young people and those over 35 years of age was due to the fact that a large number of these young underweights died of tuberculosis. It should be recognized, however, that the tuberculosis was not noted at the time of the examination and was either latent or developed subsequently. It is furthermore to be noted that the criteria of various examining physicians regarding acceptance for life insurance differ widely.

With Squad A at their minimum weight, the most marked case of underweight was that of *Tom*, with a deficiency of 12 kg., or approximately 25 pounds. *Pec* had an underweight of 8.7 kg., or 19 pounds, and *Moy* had an underweight of 8 kg. (approximately 17 pounds). Since *Pec* was 44 years old, we find from the tables of the Medico-Acturial Mortality Investigation that his underweight was advantageous, for it gave him a better expectancy of life. *Moy* and *Tom*, who were younger, may be considered, on the same authority, as having an expected mortality greater than normal. (See table 9, p. 207.)

According to the standards established by the Medico-Actuarial Mortality Investigation, therefore, the underweight of most of our subjects would be disadvantageous. As previously stated, Mr. Hunter found that a considerable proportion of the underweights included in these tables died of tuberculosis. Whether the low weight was due to the latent tuberculosis or was simply a contributing factor can not now be determined. The tables of the Medico-Actuarial Mortality Investigation were, however, based upon deficiencies in weight which were due to normal uncontrolled causes, and the underweight of our subjects was the result of a designedly reduced diet. While the fact should not be lost sight of that underweight with young individuals, not produced by design, leads to a high mortality, one can not say definitely that the underweight due to the low diet given our subjects was an actual disadvantage.

ANTHROPOMETRIC DATA.

With a degree of emaciation amounting to a loss in body-weight of 10 or more per cent, one would normally expect a visualization of this loss not only in the face, which is undoubtedly one of the most sensitive indices of changes in body-weight, but in the appearance of the whole body. This was noted in all instances. To indicate the true body condition of these men, not only when they were on normal diet but likewise during the period of diet restriction, an extensive series of measurements of each subject, including lengths and girths,

was desirable. Such a series was made for the special purpose of securing data for computing the surface area according to the formula of Du Bois.[1] Since the landmarks used by Du Bois are thoroughly established and well known to all anatomists, and their measurements give several rather characteristic circumferences or girths, this series of records may be used not only for computing the body-surface, but to show, as the research progressed, the change in body-measurements, particularly in the girths, due to the degree of emaciation.

It is the custom of many anatomists and physiologists to use other circumferences and lengths and from these to compute various indices of nutrition, but lack of time prohibited our obtaining further measurements, for this series had to be made as a part of the extremely full program of these men during their Saturday evening sojourn in Boston. We believe, however, that the Du Bois measurements, which are now coming to be considered as standards in physiology, give all the data that can normally be required.

Additional information regarding the body condition of our subjects was supplied by a series of special photographs which were made on the same days as the Du Bois measurements, in accordance with a method previously outlined,[2] and showed the subjects in profile, with left arm extended. Conference with Professor Elmer Berry, of the Y. M. C. A. College, has led us to believe that these photographs, while perhaps not strictly in accord with the usage of physical directors, are nevertheless sufficiently characteristic to indicate the general muscular condition of the subjects. Furthermore, by a method devised by one of us and subsequently described (see p. 242), these photographs have been used for computing the body-surface of the subjects, thus supplying a control upon the body-surface data computed from the Du Bois measurements.

Finally, for further comparison the predicted surface areas have been drawn off from the height-weight chart more recently devised by the Du Boises,[3] which is based upon their earlier series of measurements.

We have therefore been able to secure accurate information regarding the effect of diet restriction upon the body condition of these men by means of three methods: (1) The Du Bois measurements, which show variations in circumferences and lengths and, by computation with the factors in the Du Bois linear formula, the changes in surface area; (2) the photographic method, which supplies visual evidence and, by computation, body-surface data for comparison with the data secured by the Du Bois method; (3) the Du Bois height-weight chart, which gives the body-surfaces of these men, based upon the heights and weights of the individual subjects.

[1] Du Bois and Du Bois, Arch. Intern. Med., 1915, **15**, p. 868.
[2] Benedict, Am. Journ. Physiol., 1916, **41**, p. 275.
[3] Du Bois and Du Bois, Arch. Intern. Med., 1916, **17**, p. 863.

GENERAL BODY CONDITION.

The Du Bois measurements were made for both squads prior to and at the end of the dietetic restriction. With Squad A another series was made at the time of the minimum level. The individual data obtained for the men in Squad A are given in table 13, for the men in Squad B in table 14, and for *Fre*, *Lon*, and *McM*, in table 15. With Squad A the measurements were made on September 29, November 24, and February 2. Several members of Squad A were not measured on all three days. Thus *Fre* was measured only at the beginning of the experiment, while the first measurement for *Kon* was on October 27, instead of September 29, and *Spe*, owing to illness, was not measured on February 2. These were, however, the only exceptions.

A typical series of Du Bois measurements is given in table 16. The series of measurements selected was made with *Can*, as his percentage loss in weight was larger than that of any other member of the squad, both at the minimum weight and at the end of the experiment. These observations were made on September 29, 1917, and indicate the character of each measurement. In the tables the measurements are referred to by the letters *A*, *B*, *F*, *G*, *H*, etc., corresponding to their designation in the typical measurements of *Can*.

The changes in the body measurements made according to the Du Bois method, as the period of reduced diet progressed, are clearly shown for Squad A by a comparison of the data in table 13, particularly those for the circumferences. Practically every girth decreased perceptibly as the research continued. Attention must, however, be called to the fact that certain anomalous measurements appear even in the lengths, but so large a group of measurements enters into the computation of the surface area that, unless a gross error is made in some of the important lengths or circumferences, the variations will have but little influence upon the general accuracy of the value for the total area. These discrepancies are referred to, not so much to lay stress upon their actual mathematical value, which is practically slight, but to emphasize the fact that the traction of the tape and the exact duplication of location are not always the same when two observers are measuring an individual. It was our custom to have each subject measured by two persons and the readings taken were checked. The traction of the tape, however, will always be subject to variation. Furthermore, certain of the landmarks are not always easily recorded to less than a centimeter, particularly some of the greater lengths. On the whole, however, we believe that the measurements are accurate and supply reliable data for computing the body-surface of these men.

As would be expected, the largest losses are found with the maximum trunk girths, *i. e.*, *M*, *N*, and *Q*, and the girth at the perineum, *P*.

TABLE 13.—*Body-surface measurements (Du Bois) for Squad A.*

Subject and date.	A	B	F	G	H	I	J	K	L	M	N	P	Q	W	R	S	T	U	V	Area computed from formula.	Body-weight without clothing.	Height.
BRO.	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*sq. m.*	*kg.*	*cm.*
Sept. 29..	63.0	55.0	55.5	30.0	26.4	16.0	18.7	20.8	51.5	73.1	84.9	52.6	90.3	44.5	45.1	34.0	25.3	23.5	21.0	1.69	61.8	167.2
Nov. 24..	64.0	55.4	55.5	27.1	25.0	15.0	18.3	20.6	53.0	67.0	80.7	49.5	85.9	44.0	45.5	33.0	25.8	22.5	20.3	1.62	55.5	166.4
Feb. 2..	64.5	55.0	56.4	27.2	25.3	15.2	18.5	20.8	51.6	67.0	81.0	49.7	85.8	43.0	45.5	33.5	25.5	23.0	19.5	1.61	55.5	166.7
CAN.																						
Sept. 29..	66.8	56.5	59.2	33.2	28.4	18.4	20.9	22.2	60.4	86.5	94.7	60.1	99.0	42.0	49.7	36.5	26.9	24.0	23.5	2.03	79.8	176.9
Nov. 24..	66.2	55.4	60.0	29.3	26.7	17.0	20.7	22.1	59.5	75.7	87.2	55.5	92.4	41.0	49.3	35.0	27.5	23.1	22.5	1.87	70.5	177.1
Feb. 2..	66.7	55.2	59.1	30.0	26.5	17.6	20.2	22.0	57.5	76.2	88.1	55.0	95.0	41.7	48.6	35.6	27.5	23.0	22.2	1.86	70.3	177.5
KON.																						
Oct. 27..	69.0	57.3	59.0	32.0	28.2	17.2	20.5	20.9	56.5	74.0	90.7	57.5	93.1	39.0	46.4	36.8	25.3	23.5	21.3	1.83	69.0	167.2
Nov. 24..	66.1	58.2	58.5	29.4	27.4	16.7	20.5	20.6	56.2	70.8	85.7	53.5	89.0	39.7	46.0	34.3	27.0	23.0	21.3	1.75	65.0	167.6
Feb. 2..	68.6	58.1	57.1	29.9	27.2	16.5	19.7	21.0	55.4	71.0	84.4	52.2	88.1	40.6	46.1	33.6	25.3	23.1	20.4	1.72	62.2	167.6
GAR.																						
Sept. 29..	67.8	56.7	55.2	31.7	28.2	18.5	20.5	22.0	56.0	77.6	94.5	57.2	93.0	42.8	45.4	35.4	26.2	23.0	22.5	1.86	71.3	170.5
Nov. 24..	66.2	56.4	54.8	28.7	26.3	17.5	20.3	21.1	58.6	70.3	88.0	51.8	87.8	40.2	43.8	32.6	26.7	23.3	21.5	1.74	64.0	171.5
Feb. 2..	66.1	56.4	54.2	29.7	26.8	17.7	20.5	21.4	57.8	70.0	87.6	51.7	88.6	40.0	44.2	33.1	26.5	23.7	21.7	1.74	63.9	171.1
GUL.																						
Sept. 29..	67.5	55.4	56.7	33.5	28.1	18.2	20.2	22.4	51.2	79.5	88.7	58.3	94.1	43.7	46.0	35.5	24.8	23.0	21.7	1.81	66.8	166.0
Nov. 24..	65.5	55.5	56.0	28.5	26.5	17.0	20.0	21.5	51.2	74.0	83.0	54.5	89.5	43.7	47.0	34.0	25.0	23.0	21.2	1.71	61.0	164.8
Feb. 2..	64.6	54.7	54.4	30.1	26.4	17.2	19.7	21.6	52.7	76.3	83.1	55.7	90.5	43.1	45.4	33.6	25.4	24.2	21.3	1.72	61.8	165.9
MON.																						
Sept. 29..	69.0	59.5	56.5	32.2	27.5	16.8	19.9	21.0	58.1	77.7	91.5	55.0	90.8	46.3	44.8	34.0	25.5	22.8	21.0	1.88	68.8	170.5
Nov. 24..	69.1	58.3	56.5	30.0	25.8	16.6	20.7	20.7	57.0	71.2	86.4	49.2	86.6	45.0	44.3	33.5	26.3	21.5	20.3	1.76	61.5	170.5
Feb. 2..	68.3	58.5	56.7	30.2	26.0	16.5	20.0	20.8	57.6	73.2	87.7	49.7	86.7	44.3	44.2	34.2	26.3	22.2	20.3	1.78	61.4	170.5
MOY.																						
Sept. 29..	66.7	60.3	57.0	28.5	25.6	16.3	20.0	21.1	56.1	71.8	87.0	53.6	90.5	43.0	48.7	35.2	26.0	23.9	21.0	1.79	63.5	174.3
Nov. 24..	67.8	60.0	59.0	26.6	24.1	15.3	19.8	21.0	56.0	65.0	83.5	47.7	84.2	43.2	48.3	34.1	25.8	21.5	19.9	1.70	57.0	175.4
Feb. 2..	67.3	59.5	57.5	25.5	24.2	15.6	19.6	21.2	55.8	67.5	83.2	49.2	86.1	43.2	45.3	33.3	25.8	22.5	20.2	1.68	58.5	174.3

PEA.																						
Sept. 29..	69.2	58.5	54.5	33.5	27.8	18.3	20.2	21.5	56.4	76.3	95.5	55.8	95.3	41.8	46.5	36.9	25.5	23.3	22.3	1.88	69.3	168.5
Nov. 24..	67.3	58.5	53.6	30.8	25.7	17.1	19.6	20.8	55.8	69.8	90.5	51.3	90.2	41.0	45.9	34.1	25.6	23.1	21.5	1.74	62.8	169.1
Feb. 2..	68.7	59.7	55.4	29.5	26.3	17.2	19.0	21.1	54.4	72.0	91.0	52.0	90.0	41.5	46.2	35.2	25.8	23.1	21.4	1.76	62.3	169.0
PEC.																						
Sept. 29..	65.8	56.9	57.8	28.8	26.5	17.0	20.6	22.7	58.5	73.0	87.7	53.5	91.0	42.1	49.0	36.5	25.5	24.1	22.0	1.84	64.3	170.1
Nov. 24..	66.1	56.9	58.6	26.1	25.1	16.4	20.8	21.6	56.7	67.6	84.6	49.9	85.7	42.2	47.7	35.8	26.5	23.0	21.3	1.74	60.0	170.7
Feb. 2..	65.5	57.1	57.2	25.8	25.2	16.1	20.7	21.8	57.3	70.9	84.5	48.3	86.7	41.3	47.5	35.1	25.7	23.5	21.3	1.74	60.0	170.7
SPE.																						
Sept. 29..	65.3	55.7	58.5	30.0	25.3	16.5	20.8	20.6	55.2	73.3	88.7	55.5	90.3	42.5	47.7	35.5	25.0	22.8	20.8	1.79	63.5	171.1
Nov. 24..	62.9	55.5	60.6	25.4	22.7	15.4	20.0	20.3	57.2	64.8	83.3	48.8	84.3	40.9	48.8	33.5	25.7	21.8	19.5	1.67	55.8	171.8
TOM.																						
Sept. 29..	62.0	56.5	59.5	28.5	25.2	17.0	21.0	21.2	57.2	67.8	89.0	52.0	86.5	44.8	49.0	34.7	25.5	22.8	21.0	1.79	59.5	175.6
Nov. 24..	66.1	55.0	58.0	25.6	23.6	16.4	20.3	21.0	57.8	64.2	80.1	48.7	83.1	44.0	47.9	33.0	26.8	23.0	20.6	1.69	56.0	175.9
Feb. 2..	66.7	56.1	57.5	26.1	23.4	16.8	19.5	21.0	56.5	64.5	81.5	48.5	84.0	43.0	48.5	33.0	26.1	22.5	20.3	1.67	55.9	175.5
VEA.																						
Sept. 29..	66.5	58.0	58.0	29.0	26.0	17.5	21.7	21.3	57.0	75.0	88.2	54.0	91.5	44.5	47.0	34.5	25.2	24.0	23.0	1.84	65.8	174.9
Nov. 24..	65.6	57.9	58.2	26.9	24.4	17.2	21.1	20.7	56.1	68.3	83.6	49.8	87.1	43.5	46.2	33.6	26.3	22.5	21.7	1.72	60.3	174.3
Feb. 2..	67.3	58.3	59.2	27.4	24.6	17.4	21.6	21.1	54.5	69.0	84.0	48.7	87.5	45.6	47.3	34.5	26.3	22.7	21.8	1.75	59.3	174.2

TABLE 14.—*Body-surface measurements (Du Bois) for Squad B.*

Subject and date.	A	B	F	G	H	I	J	K	L	M	N	P	Q	W	R	S	T	U	V	Area computed from formula.	Body-weight without clothing.	Height.
FIS.	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*sq. m.*	*kg.*	*cm.*
Jan. 5..	69.8	58.3	56.9	32.9	28.9	18.3	21.2	22.4	58.2	79.9	93.6	58.0	98.3	38.6	48.0	37.0	26.3	23.7	22.3	1.93	76.3	176.1
Jan. 27..	68.0	57.5	58.5	30.5	27.6	17.8	20.7	22.0	58.7	74.2	89.0	52.5	94.5	39.0	48.0	36.0	26.2	23.0	21.5	1.85	72.3	175.9
HAR.																						
Jan. 5..	64.9	54.9	58.2	30.4	28.2	17.5	20.4	22.1	58.0	71.5	88.4	57.5	91.1	43.2	46.1	35.3	25.0	23.2	21.7	1.83	63.7	173.9
Jan. 27..	64.0	53.8	58.1	28.5	26.8	16.9	20.3	22.1	57.5	67.6	86.6	55.0	88.1	43.3	45.4	33.8	24.5	22.9	20.8	1.75	59.6	173.7
HOW.																						
Jan. 5..	66.7	57.5	59.2	31.1	28.0	17.1	20.4	21.6	58.2	77.3	93.5	59.0	99.1	41.4	51.0	36.7	27.0	24.8	23.4	1.95	72.0	178.3
Jan. 27..	66.9	57.1	58.2	28.9	26.4	16.4	20.0	21.0	57.5	72.0	89.0	56.3	94.6	43.0	50.3	35.0	26.5	23.8	22.5	1.85	66.6	178.0
HAM.																						
Jan. 5..	69.5	59.5	61.6	32.2	27.2	17.3	21.0	20.6	59.9	77.7	93.6	59.9	99.4	44.5	47.8	33.8	26.5	23.4	21.1	1.97	74.8	183.2
Jan. 27..	68.9	59.1	62.2	30.0	26.3	17.1	19.4	20.8	61.8	73.7	90.9	59.0	95.3	43.8	48.8	33.9	26.7	23.8	21.1	1.94	70.7	183.1
KIM.																						
Jan. 5..	69.2	57.2	61.4	27.5	26.0	15.1	20.6	19.6	55.7	73.0	85.4	51.0	89.7	43.8	49.7	34.3	25.5	23.0	20.7	1.78	61.9	175.6
Jan. 27..	68.5	56.6	59.8	26.0	24.7	15.2	20.3	19.8	55.5	69.6	83.0	48.5	87.6	44.0	48.3	32.7	25.5	21.0	19.5	1.70	60.7	175.6
SCH.																						
Jan. 5..	69.1	56.1	55.8	32.2	28.7	18.0	21.2	22.6	53.5	74.6	97.4	55.5	93.0	42.5	44.6	36.2	26.5	24.0	21.4	1.84	68.6	166.0
Jan. 27..	69.2	56.5	56.3	31.3	27.5	17.9	21.1	22.1	53.1	72.9	93.1	51.1	89.3	43.0	44.4	35.0	26.8	23.1	20.8	1.78	64.2	165.3
LIV.																						
Jan. 5..	66.7	58.1	54.0	30.8	26.7	17.2	18.4	19.1	55.9	74.8	92.1	56.3	92.1	38.3	41.8	32.9	24.0	22.3	20.2	1.71	63.6	161.1
Jan. 27..	65.5	57.4	53.0	27.2	25.0	15.7	18.5	19.0	55.0	69.5	88.0	49.5	85.5	39.5	43.0	31.0	24.2	21.5	19.5	1.61	59.3	160.9
SNE.																						
Jan. 5..	65.0	54.8	58.2	32.5	28.5	18.0	19.5	20.8	57.4	75.6	94.5	60.2	98.2	43.8	46.0	36.8	24.2	23.0	21.0	1.90	72.9	174.9
Jan. 27..	63.3	53.2	57.7	30.4	27.0	17.0	19.5	20.2	56.0	70.3	88.2	55.0	93.0	44.5	45.7	34.8	24.2	22.4	20.0	1.77	68.4	174.0

Tʜᴏ.																						
Jan. 5..	65.9	57.0	60.2	27.8	25.5	17.2	20.8	21.1	55.3	71.1	87.7	53.6	90.4	44.4	52.0	36.4	26.8	23.4	21.4	1.83	63.2	177.9
Jan. 27..	65.5	56.8	61.5	27.0	25.0	17.0	20.8	20.8	55.0	69.0	84.4	50.4	88.5	44.0	51.4	35.0	26.7	23.1	20.3	1.77	59.9	177.5
Vᴀɴ.																						
Jan. 5..	66.9	56.2	60.3	30.0	27.2	17.9	20.8	22.0	56.0	74.6	92.1	53.6	94.6	46.3	47.1	34.4	26.8	25.2	21.4	1.89	69.8	178.7
Jan. 27..	67.4	55.8	62.5	28.0	26.2	17.0	20.2	21.6	58.5	71.2	88.7	50.3	91.2	46.2	47.0	34.0	27.0	23.9	21.0	1.85	65.4	178.4
Wɪʟ.																						
Jan. 5..	65.5	55.0	51.9	29.2	26.5	16.7	18.6	20.5	55.1	70.2	88.0	53.3	89.5	38.7	43.3	34.4	24.7	22.5	19.7	1.66	59.8	164.0
Jan. 27..	64.5	54.5	52.0	28.0	25.5	15.7	18.5	19.5	53.5	67.0	82.5	49.5	86.5	41.0	43.5	33.0	24.5	21.4	19.2	1.58	57.1	164.0

Tᴀʙʟᴇ 15.—*Body-surface measurements (Du Bois) for Fre, Lon, and McM.*

Subject and date.	A	B	F	G	H	I	J	K	L	M	N	P	Q	W	R	S	T	U	V	Area computed from formula.	Body-weight without clothing.	Height.
Fʀᴇ.	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*sq. m.*	*kg.*	*cm.*
Sept. 29..	66.7	56.2	58.0	29.1	25.6	15.5	20.2	20.2	53.7	68.7	87.4	49.0	83.3	43.9	43.9	33.3	24.5	21.8	19.3	1.67	57.5	167.1
Lᴏɴ.																						
Jan. 27..	67.1	54.2	60.0	28.5	26.3	17.2	21.4	21.0	57.8	66.8	91.8	49.4	88.0	43.0	49.5	34.0	25.7	22.5	20.0	1.80	63.8	178.4
McM.																						
Jan. 5..	66.5	57.0	55.5	31.2	27.5	17.2	18.5	21.2	56.0	76.3	86.4	55.2	95.1	42.0	44.8	34.8	26.0	22.0	22.8	1.79	68.8	169.8

TABLE 16.—*Du Bois linear formula to determine surface area.*

Subject, Kenneth B. Canfield. Date, Sept. 29, 1917.
Nude weight (kg.), 79.75. Height (cm.), 176.9.
Surface area (sq. m.), linear formula, 2.03; height-weight chart, 1.97.

	Cm.	Log.	Sq. cm.
Head 0.308		48855	Head 1,162
AB 0.308 A Around vertex and chin	66.8	82478	Arms 2,894
B Occiput and forehead	56.5	75205	Hands 1,030
			Trunk 7,694
		06538	Thighs 3,689
			Legs 2,540
Arms 0.611		78604	Feet 1,329
F (G+H+I) 0.611 F Acromium process to lower border radius	59.2	77232	20,338
G Circumference at axilla .. 33.2 H Largest of forearm ...... 28.4 I Smallest of forearm 18.4	80.0	90309	=2.034 sq. m.
		46145	
Hands 2.22		34635	
JK 2.22 J Radius to tip second finger	20.9	32015	
K Circumference hand at knuckles	22.2	34635	
		01285	
Trunk 0.703		84696	
L (M+N) 0.703 L Suprasternal notch to pubes	60.4	78104	
M Circumference at umbilicus ...... 86.5 N Circumference at nipples 94.7	181.2	25816	
		88616	
Thighs 0.552		74194	
W (P+Q) 0.552 W Superior border pubes to lower border patella	42.0	62325	
P Circumference at perineum ...... 60.1 Q Circumference hips and buttocks 99.0	159.1	20167	
		56686	
Legs 1.40		14613	
RS 1.40 R Sole of foot to lower border patella	49.7	69636	
S Circumference at lower border patella	36.5	56229	
		40478	
Feet 1.04		01703	
T (U+V) 1.04 T Length of foot	26.9	42975	
U Circumference base fifth toe ...... 24.0 V Smallest circumference ankle 23.5	47.5	67669	
		12347	

The girth at the axilla, G, likewise shows a considerable loss. To bring out more sharply the changes in these measurements as the research progressed, the final losses in these particular circumferences have been tabulated in table 17, together with the initial body-weights

TABLE 17.—*Final losses in weight and circumferences, Squads A and B.*

Subject.	Initial body-weight.	Final loss in body-weight.	Decrease in circumferences.[1]					
			Axilla (G).	Umbilicus (M).	Nipples (N).	Perineum (P).	Hips and buttocks (Q).	Average.
Squad A:	*kg.*	*p. ct.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*
Bro	61.8	12.0	2.8	6.1	3.9	2.9	4.5	4.0
Can	79.8	13.2	3.2	10.3	6.6	5.1	4.0	5.8
Kon	69.0	10.9	2.1	3.0	6.3	5.3	5.0	4.3
Gar	71.3	11.6	2.0	7.6	6.9	5.5	4.4	5.3
Gul	66.8	8.7	3.4	3.2	5.6	2.6	3.6	3.7
Mon	68.8	11.9	2.0	4.5	3.8	5.3	4.1	3.9
Moy	63.5	9.0	3.0	4.3	3.8	4.4	4.4	4.0
Pea	69.3	11.5	4.0	4.3	4.5	3.8	5.3	4.4
Pec	64.3	8.1	3.0	2.1	3.2	5.2	4.3	3.6
Spe	63.5	[2]12.4	4.6	8.5	5.4	6.7	6.0	6.2
Tom	59.5	7.4	2.4	3.3	7.5	3.5	2.5	3.8
Vea	65.8	11.1	1.6	6.0	4.2	5.3	4.0	4.2
Average	67.0	10.7	2.8	5.3	5.1	4.6	4.3	4.4
Squad B:								
Fis	76.3	6.0	2.4	5.7	4.6	5.5	3.8	4.4
Har	63.7	7.2	1.9	3.9	1.8	2.5	3.0	2.6
How	72.0	8.1	2.2	5.3	4.5	2.7	4.5	3.8
Ham	74.8	6.6	2.2	4.0	2.7	.9	4.1	2.8
Kim	61.9	3.2	1.5	3.4	2.4	2.5	2.1	2.4
Sch	68.6	7.0	.9	1.7	4.3	4.4	3.7	3.0
Liv	63.6	7.9	3.6	5.3	4.1	6.8	6.6	5.3
Sne	72.9	7.1	2.1	5.3	6.3	5.2	5.2	4.8
Tho	63.2	6.2	.8	2.1	3.3	3.2	1.9	2.3
Van	69.8	7.2	2.0	3.4	3.4	3.3	3.4	3.1
Wil	59.8	4.8	1.2	3.2	5.5	3.8	3.0	3.3
Average	67.9	6.5	1.9	3.9	3.9	3.7	3.8	3.4

[1] With Squad B all decreases were found at the period of minimum weight after 3 weeks of reduced diet.
[2] *Spe* withdrew from Squad A on December 15, owing to illness.

and the final percentage losses in body-weight. The losses in the girth G with Squad A ranged from 4.6 to 1.6 cm., with an average loss for the group of 2.8 cm. With M (the circumference at the umbilicus) we have losses ranging from 10.3 cm. with *Can*, who was distinctly overweight and fat, to a minimum of 2.1 cm. with *Pec*, who was a thoroughly well-trained and hardened athlete, and distinctly "fine" at the beginning of the experiment. The average loss in this measurement for the whole group is 5.3 cm.

The largest loss in the circumference at the nipples, N, is that of *Tom*, of 7.5 cm., which is somewhat singular, inasmuch as this sub-

ject was fairly thin at the beginning of the study. The minimum is again found with *Pec*, *i. e.*, 3.2 cm., while the average loss for the whole group is 5.1 cm.

The maximum loss for *P*, the girth at the perineum, occurred with *Spe*, 6.7 cm., while the minimum is with *Gul*, 2.6 cm. The average for the group is 4.6 cm. The largest loss in the circumference at the hips and buttocks, *Q*, is again found with *Spe*, with a decrease of 6.0 cm., and the minimum with *Tom*, with a loss of 2.5 cm. The average for the group is 4.3 cm.

When averaged somewhat arbitrarily, the losses in the five main circumferences for the whole group show a maximum loss with *Spe* of 6.2 cm., followed closely by *Can*, with 5.8 cm., with a minimum for *Pec*, the highly trained athlete, of 3.6 cm. The average for the group is 4.4 cm.

While in general many of the measurements show decreases roughly approximate to the percentage loss in body-weight, in certain instances the decrease is quite contrary to the percentage loss in body-weight. This is particularly true of the measurement *N* with *Tom*, this subject showing a larger decrease in this measurement than any other subject, although he had the smallest body-weight and his percentage loss in body-weight was the smallest. From a general inspection of the data no striking uniformity appears. Apparently no simple mathematical relationship between the decreases in girth and either the total loss or the percentage loss in body-weight may be established.

The period of loss in weight for Squad B was approximately 21 days. The losses in weight and in the five major girths during this period with these subjects are also given in table 17, together with the initial body-weight and percentage loss in weight. While a direct comparison of these losses is hardly justifiable, since the men were not of the same general contour, yet it is evident that the decreases are less than those found for Squad A. The final percentage loss in body-weight for this squad was but 6.5 per cent, as compared with 10.7 per cent with Squad A. If we take as a general index of decrease in these measurements the averages of the values for *G*, *M*, *N*, *P*, and *Q*, we find that they range from a maximum of 5.3 cm. with *Liv*, to a minimum of 2.3 cm. for *Tho*, the average for the whole group being 3.4 cm. This is perceptibly smaller than the average for Squad A, which was 4.4 cm.

The degree of emaciation produced by the restriction in diet may also be shown to some extent by means of the profile photographs given in figures 74 to 85. These were taken of the men in Squad A at the end of the experiment, *i. e.*, on February 2, 1918. For comparison, a photograph is also given of one subject (*Can*) which was taken on September 29, before the restriction in diet began. A loss in weight of 10 per cent or even, as with *Can*, 13 per cent, does not of

FIG. 74.—Photograph of *Can*. Sept. 29, 1917.
Beginning of experiment.

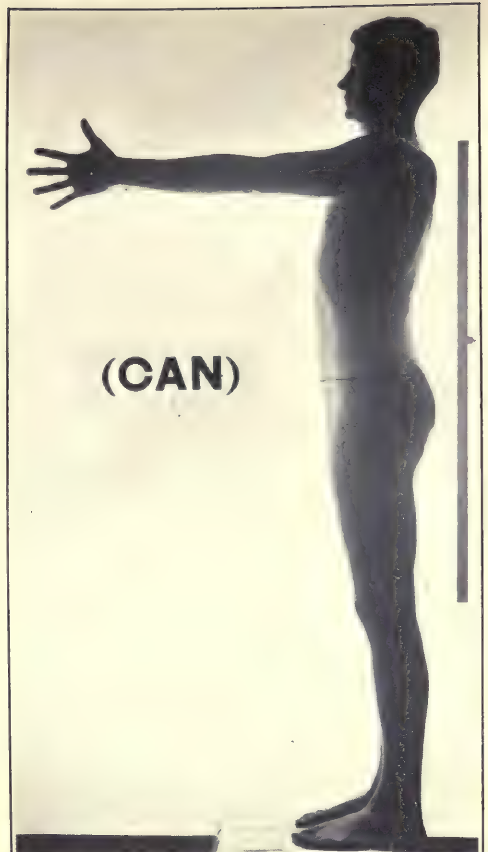

FIG. 75.—*Can*, Feb. 2, 1918.
End of experiment.

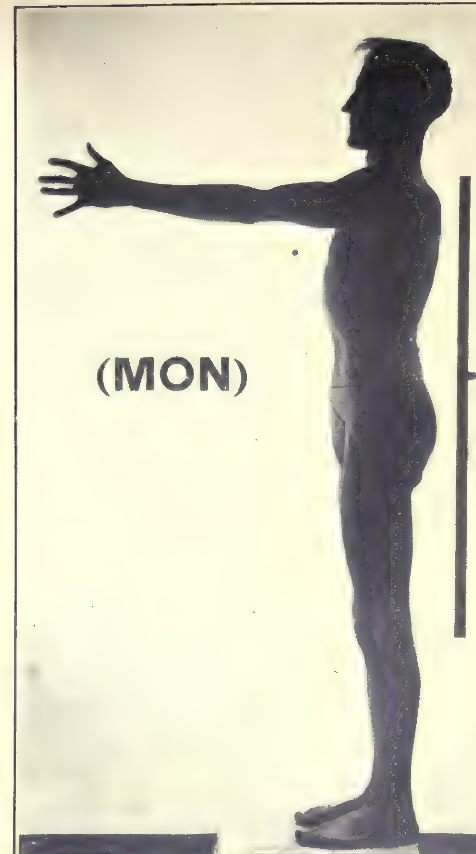

FIG. 76.—*Mon* Feb. 2, 1918.

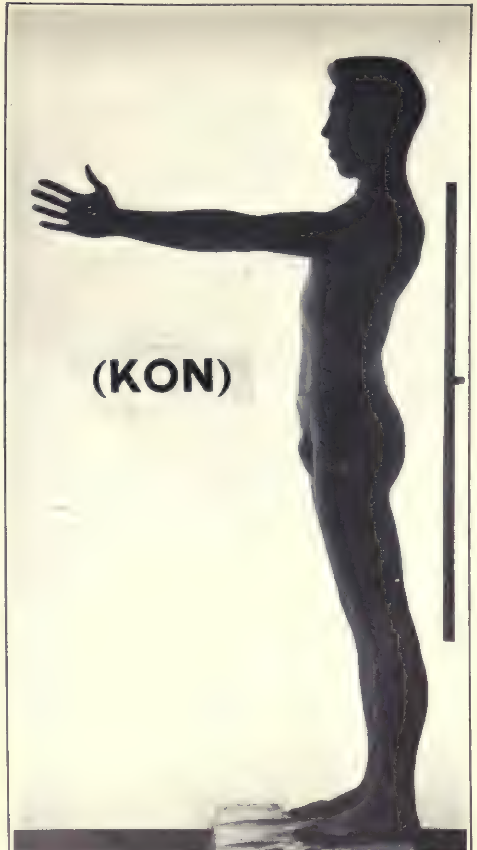

FIG. 77.—Photograph of *Kon*, Feb. 2, 1918.

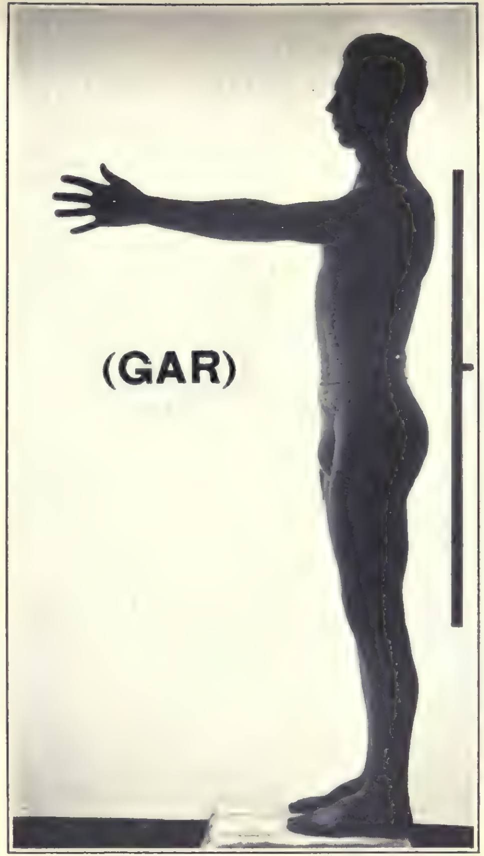

FIG. 78.—*Gar*, Feb. 2, 1918.

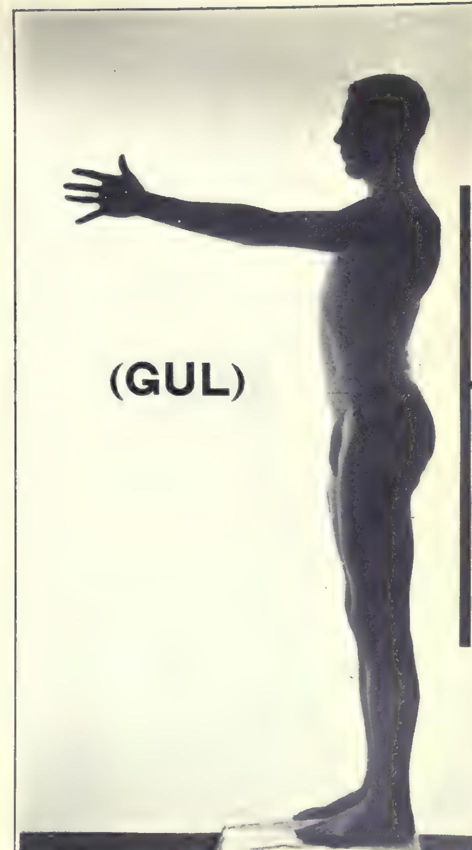

FIG. 79.—*Gul*, Feb. 2, 1918.

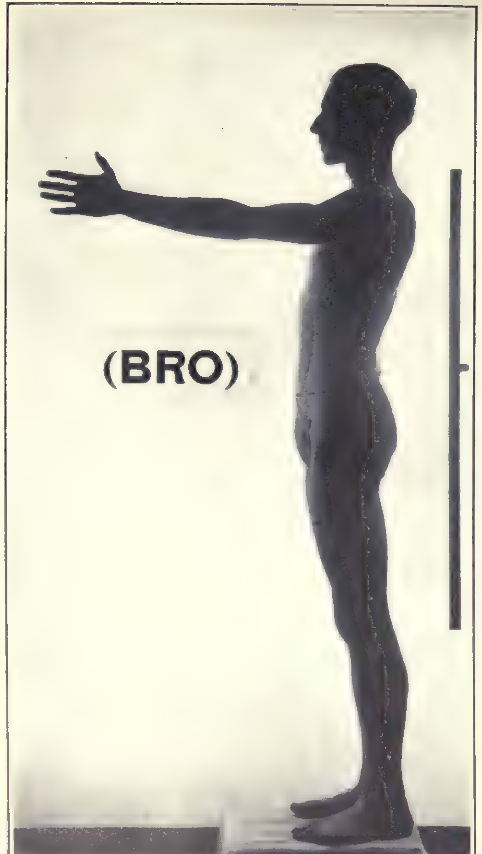

FIG. 80.—Photograph of *Bro*, Feb. 2, 1918.

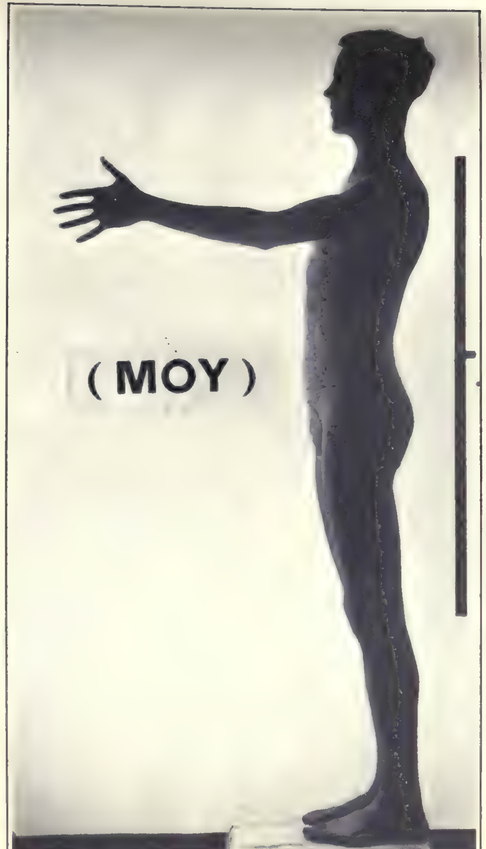

FIG. 81.—*Moy*, Feb. 2, 1918.

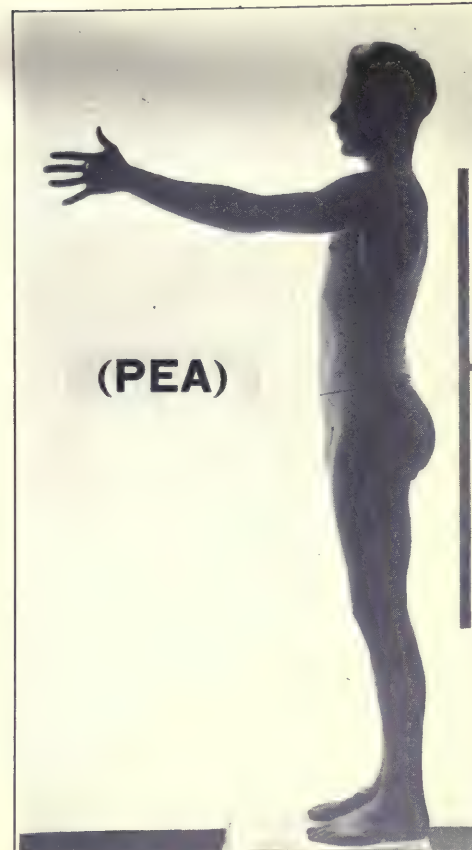

FIG. 82.—*Pea*, Feb. 2, 1918.

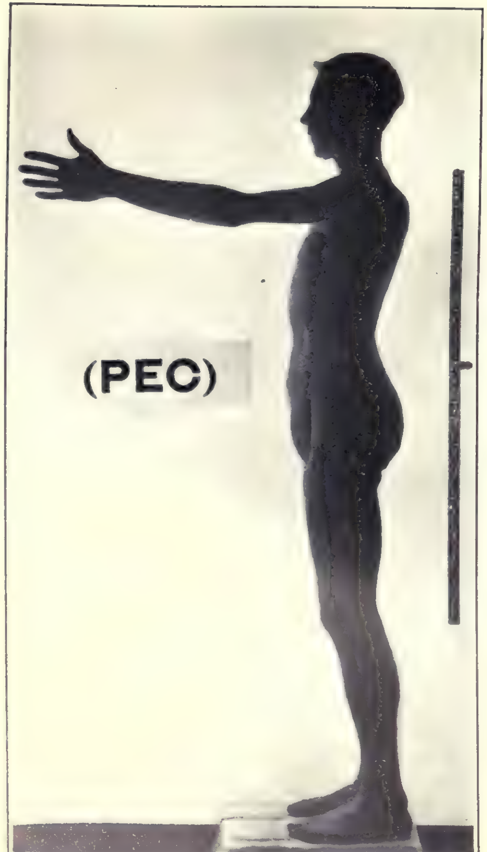

Fig. 83.—Photograph of *Pec*, Feb 2, 1918.

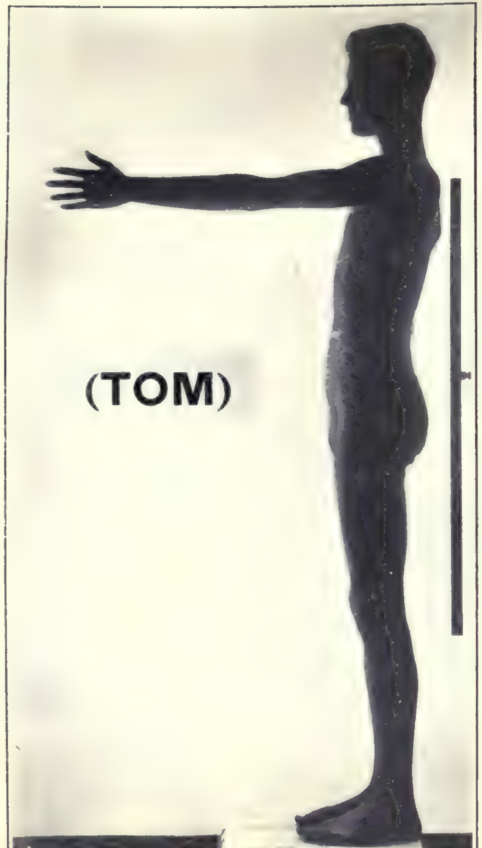

Fig. 84.—*Tom* Feb. 2, 1918.

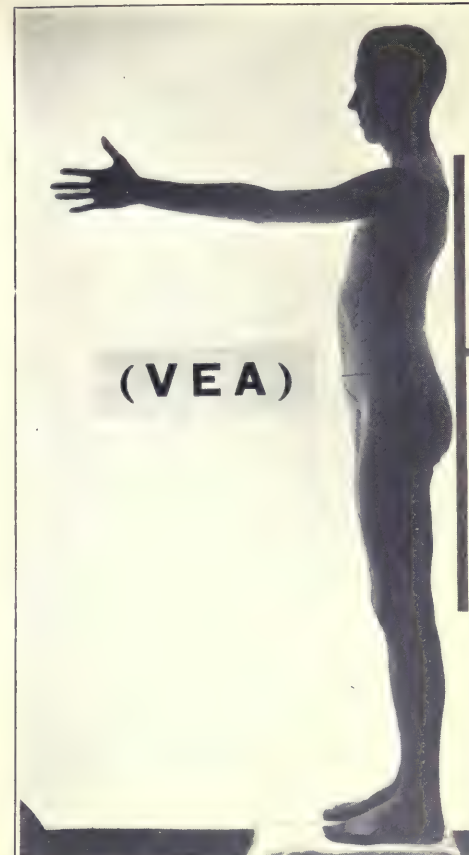

Fig. 85.—*Vea*, Feb. 2, 1918.

course, produce an effect which is especially evident. We believe, however, that photographic records of this type are important, particularly for hospital cases, and are strongly to be recommended. In reduction cures for obesity, particularly, such photographs might be of specific value.

In addition to the profile photographs, a group photograph was taken of Squad A in November, when they had nearly reached their minimum weight. This group photograph, which is reproduced in figure 86, was taken on the lawn near the Laboratory and gives a good indication of the appearance of the men at that period of the research. Knowing that these men are on a reduced diet, one may perhaps discern the evidence of emaciation, with possibly a drawn look in the face, but had these men been in company with other college men on the campus, it would have been very difficult for any one to have selected them as members of the diet squad without previous knowledge of that fact. In other words, these men were not greatly dissimilar in appearance from their fellow students. Another group photograph was taken on January 11, 1918, in which not only Squad A but also Squad B and the investigators were included. (See frontispiece.) On this date Squad B had been but 3 days on a reduced diet, and hence were practically in a normal condition.

BODY-SURFACE.

The body-surface of the men in Squads A and B has been computed both from the photographs and from the Du Bois measurements. Finally, for further comparison we have drawn off the predicted surface areas from the height-weight chart. These values are given in tables 18 and 19. The method of computing the body-surface from

TABLE 18.—*Body-surface measured by different methods—Squad A.*

Subject.	Du Bois linear formula.			Du Bois height-weight chart.			Photographic (5.02 C.).		
	Sept. 29.	Nov. 24.	Feb. 2.	Sept. 29.	Nov. 24.	Feb. 2.	Sept. 29.	Nov. 24.	Feb. 2.
	sq. m.	*sq. m.*	*sq. m.*	*sq. m.*	*sq. m.*	*sq. m.*	*sq. m.*	*sq. m.*	*sq. m.*
Bro	1.69	1.62	1.61	1.70	1.61	1.62	1.71	1.58	1.55
Can	2.03	1.87	1.86	1.97	1.87	1.87	1.99	1.83	1.87
Kon[1]	1.83	1.75	1.72	1.78	1.74	1.71	1.80	1.80	1.69
Gar	1.86	1.74	1.74	1.83	1.76	1.75	1.91	1.79	1.73
Gul	1.81	1.71	1.72	1.75	1.67	1.69	1.76	1.66	1.63
Mon	1.88	1.76	1.78	1.81	1.72	1.72	1.84	1.74	1.72
Moy	1.79	1.70	1.68	1.77	1.69	1.71	1.80	1.72	1.66
Pea	1.88	1.74	1.76	1.79	1.72	1.72	1.88	1.79	1.69
Pec	1.84	1.74	1.74	1.75	1.70	1.70	1.79	1.76	1.66
Spe	1.79	1.67	....	1.75	1.66	....	1.78	1.66	....
Tom	1.79	1.69	1.67	1.73	1.69	1.69	1.76	1.66	1.61
Vea	1.84	1.72	1.75	1.80	1.73	1.72	1.89	1.69	1.68

[1]The first body-surface measurements with *Kon* were obtained October 27.

TABLE 19.—*Body-surface measured by different methods—Squad B.*

Subject.	Du Bois linear formula.		Du Bois height-weight chart.		Photographic (5.02 C.).	
	Jan. 5.	Jan. 27.	Jan. 5.	Jan. 27.	Jan. 5.	Jan. 27.
	sq. m.	*sq. m.*	*sq. m.*	*sq. m.*	*sq. m.*	*sq. m.*
Fis.......	1.93	1.85	1.92	1.88	1.91	1.79
Har.......	1.83	1.75	1.77	1.72	1.75	1.66
How......	1.95	1.85	1.89	1.83	1.88	1.77
Ham......	1.97	1.94	1.96	1.92	1.89	1.89
Kim......	1.78	1.70	1.76	1.75	1.78	1.65
Sch.......	1.84	1.78	1.77	1.71	1.75	1.71
Liv.......	1.71	1.61	1.67	1.62	1.71	1.65
Sne.......	1.90	1.77	1.88	1.82	1.82	1.77
Tho......	1.83	1.77	1.79	1.75	1.75	1.70
Van......	1.89	1.85	1.88	1.82	1.83	1.77
Wil.......	1.66	1.58	1.65	1.62	1.58	1.59

the Du Bois measurements, also the factors used in the linear formula are shown in the typical series of measurements given in table 16. The method of computing the body-surfaces from the profile photographs is as follows:

From an extensive series of photographs and measurements of men and women it was found that when the planimetered area of a photograph giving a profile view of a subject with left arm extended[1] was referred to a photographed meter scale, its relation to the total area of the body was represented by the average factor 5.02. In other words, the area of the planimetered section referred to the meter scale, when multiplied by 5.02, gave the total area of the body as computed by the Du Bois formula. Usually in planimetering, the photograph is divided into two approximately equal parts by an arbitrarily drawn line passing through the hips. The upper and lower sections are then planimetered separately and the sum of the two areas, which on our instrument is expressed in square inches, is multiplied by the factor 6.45 for conversion to square centimeters. The length of the meter scale in the photograph is then found in millimeters and the true area of the surface shown in the photograph obtained by a simple proportion. Thus, using the photograph of Greyson C. Gardner (*Gar*, fig. 78) as an illustration, we found that the lower part of the body gave an area by planimetering of 1.78 square inches and for the upper part of 2.31 square inches, the total area of the photograph being 4.09 square inches. This, reduced to square centimeters by means of the factor 6.45, gave a total area for the photograph of 26.4 sq. cm., or 0.00264 sq. meter. The meter scale in the photograph measured 87.5 mm. or 0.0875 m. The proportion used for calculating the actual surface of the body shown in the photographs

[1] Our so-called "pose C." See Benedict, Am. Journ. Physiol., 1916, 41, p. 275.

FIG. 86.—THE DIET SQUAD (A), ON NOVEMBER 25, 1917.

On this date the men were approximately at their minimum weight. Those standing are from left to right; Moyer, Veal, Tompkins, Peckham, Montague, Canfield. Sitting, from left to right: Brown, Gullickson, Kontner, Spencer, Peabody, Gardner.

would therefore be: $l^2:1^2::a:x$, l representing the length of the metric scale as photographed (0.0875 meter), a the area of the photograph expressed in square meters (0.00264 square meter), and x the actual surface area of the section of the body shown in the photograph. The general equation would be: $x=\frac{a}{l^2}$. The actual surface area of the section of *Gar's* body shown in the photograph would thus be 0.00264 sq. meter divided by 0.00766 or 0.345 sq. meter. Using the factor 5.02, which represents the relationship found to exist between the surface of the body shown in pose *C* and the surface of the whole body, we find that the body-surface of this subject as computed from the silhouette photograph is 1.73 sq. meters.[1]

With Squad A in September, when the first measurement was obtained, the surface areas as computed by the Du Bois formula are almost invariably higher than those found by the height-weight chart, while in November, at the time of the minimum weight, these differences practically disappear. We are somewhat at a loss to understand why there should be this variation, for the measurements were made with great care, although admittedly under considerable tension. The discrepancies are, however, not very great, but singularly enough lie almost invariably in one direction. When the values computed from the Du Bois formula from the set of measurements made on February 2 are compared with those calculated from the height-weight chart, we find a very close agreement for practically all of the subjects. The widest discrepancy is that with *Mon*, the values being 1.78 sq. meters for the Du Bois formula as compared with 1.72 sq. meters found with the height-weight chart. It is further noticeable that the differences are plus or minus, that is, the averages of the two areas for the squad as a whole would be nearly the same, irrespective of whether it was determined by the Du Bois linear formula or by the height-weight chart.

With Squad B a comparison between the results obtained with the Du Bois linear formula and the height-weight chart shows, for the most part, excellent agreement. For the measurements taken January 5, *i. e.*, before weight-reduction, the widest difference is found with *Sch*, the values being 1.84 sq. meters for the Du Bois formula as against 1.77 sq. meters for the height-weight chart. With the measurements taken after the reduction in weight (January 27), there is likewise fairly uniform agreement between the results obtained on the two bases of measurement. *Sch* again shows the greatest discrepancy, with 1.78 sq. meters for the Du Bois formula, as opposed to 1.71 sq. meters for the height-weight chart. In these later comparisons, how-

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[1] Reference to the original description of the photographic method (Benedict, Am. Journ. Physiol., 1916, **41**, p. 275) should be made for the technique of taking these photographs and other details of this method of calculating the surface area.

ever, the variations are plus or minus, leaving no difference between the average areas for the whole squad when measured by either method, while on January 5 there was a tendency, as with Squad A at the beginning of the experiment, for the linear formula to give slightly higher values than with the height-weight chart.

Comparing the areas for Squad A, as obtained by the photographic method, with those computed from the Du Bois measurements, we find that there are minor variations, but that on the whole the averages of the three measurements show that the total areas as determined by the three methods are essentially alike. The averages for Squad A for September 29 are 1.84, 1.79, and 1.83 sq. meters, for the Du Bois formula, height-weight chart, and photographic method, respectively. On November 24, the averages are 1.73, 1.71, and 1.72, respectively. On February 2 the areas computed from the photographs are in most instances smaller than they are by the linear formula, the widest difference being with *Gul*, 1.72 against 1.63 sq. meters, or 0.09 sq. meter. The average areas for the three methods are 1.73, 1.72 ,and 1.68 sq. meters, respectively.

With Squad B the area computed from the photographic method on January 5 is, in almost every instance, somewhat lower than that obtained by the linear formula, the widest difference being with *Sch*, 1.84 sq. meters as against 1.75 sq. meters. The averages are 1.84, 1.81, and 1.79 sq. meters. On January 27 a comparison of the two methods likewise shows somewhat lower values with the photographic method than with the Du Bois method. The averages for the three methods are 1.77, 1.77, and 1.72 sq. meters.

In addition to the 23 subjects given in tables 18 and 19, a single series of measurements was made with three other subjects, and the body sur-

TABLE 20.—*Body-surface measurements, supplementary data.*

Subject.	Date.	Du Bois linear formula.	Height-weight chart.	Photographic (5.02C.)
Squad A:		*sq. m.*	*sq. m.*	*sq. m.*
Fre....	Sept. 29, 1917...	1.67	1.64	1.65
Squad B:				
McM..	Jan. 5, 1918.....	1.79	1.80	1.73
Lon...	Jan. 27, 1918....	1.80	1.80	1.75

face obtained by the three methods. These were *Fre*, on September 29, 1917, *McM* on January 5, and *Lon* on January 27, 1918. The values for these three subjects are given in table 20 as supplementary evidence. These values show essentially the same picture as those for the larger group of 23 men.

We may, perhaps, make the best comparison of the two methods by computing the factor to be used in the photographic method for each

date, using the Du Bois linear measurement as the basis. The photographic method, as commonly employed, uses the factor 5.02. With Squad A, the average factor for the first measurement on September 29 would be 5.05. For November 24 it would be 5.03 and for February 2, 5.17. With Squad B the average factor would be, for January 5, 5.19, and for January 27, 5.15.

Since the factor of 5.02, originally derived, was obtained from rather a large number of individuals (20 in all) of grossly varying surface conditions, it is perhaps somewhat surprising that with the more homogeneous material supplied by the subjects in tables 18 and 19, the same average factor is not obtained. Two important points should be considered in this connection, first, that the profile photographs with both Squads A and B were made with artificial light in the laboratory at night, by hanging a large sheet on a frame, and placing behind it an M-type Cooper-Hewitt lamp. This method of illumination was by no means so satisfactory as the daylight method used for the earlier series in which the photographic method was developed and a white sheet was hung before a window. Secondly, the pictures were taken principally to show the general physical contour of these men and not with the special care necessary for their use in accurate photographic measurements, a precaution which should have been taken. Finally, when it is considered that these 12 men were photographed in the nude a few minutes before they entered the respiration chamber at night, and that they were peculiarly sensitive to cold, it will be seen that the photographing was inevitably hastened too much for the best results. Consequently, care was not always taken to place the metric scale exactly opposite the backbone of the subject. Furthermore, it was found necessary to focus the camera on the pedestal upon which the men stood and then take all the photographs without refocusing for each subject. We believe that these considerations sufficiently explain the variations from the average 5.02 noted in the development of the formula by the photographic method.

As a check upon the Du Bois measurements, however, the photographic measurements are very helpful. Attention should be called to the almost uniform agreement in the Du Bois measurements with Squad A for November 24 and February 2. It is a gratifying verification of these measurements to note that they can be made with a squad of 12 men some 10 weeks apart and still show such uniform agreement with each other. It will be remembered that there was a negligible difference in weight of these men on November 24 and February 2.

BODY TEMPERATURE.

The sensation of cold, which was noted throughout a good part of the research by practically all of the men, made a study of body temperature of special significance. Each morning, prior to the measure-

ments of the respiratory exchange, the oral temperature of the subject was taken with a standard clinical thermometer. These records were made simply to eliminate the possibility of measuring the gaseous exchange when the subject was in a slightly febrile or febrile condition, and not with a view to determining the physiological temperature, for as is well known, mouth temperatures have no definite physiological value.

Throughout the entire series abnormal temperatures were rarely found. Occasionally slightly febrile temperatures were noted when the subject was suffering from a cold; under these conditions the gaseous metabolism was not measured. With *Spe* abnormal body temperatures were recorded for a number of days prior to his leaving for home in consequence of suspected typhoid infection.

RECTAL TEMPERATURE MEASUREMENTS.

In contrast to the temperature measurements taken in the mouth, the temperature measurements made in the rectum were of true physiological significance. These were obtained at the end of the night experiments with the respiration chamber in Boston and just before the subject arose in the morning. For this purpose 12 accurate clinical thermometers were used; all of these thermometers had previously been carefully calibrated with a standard Richter thermometer. Owing to the darkness of the chamber it was impossible for the experimenters to insert the thermometer personally. After the bulbs of the thermometers had been coated with vaseline, each man was instructed to insert a thermometer more than half its length in the rectum. Inasmuch as the men were an unusually intelligent group and thoroughly appreciative of the importance of the experiment, we have reason to believe that the thermometers were in all instances satisfactorily inserted and that the temperature recorded may be taken as a true measure of the rectal temperature of these men. After the thermometers had been removed they were carefully read and checked by a second person before the records were finally made.

The special advantages of taking rectal temperatures under these conditions were, first, that the subjects had all received a constant standard meal at 5 p. m. the night before. Furthermore, they were lying on the beds inside the chamber for not less than 7 to 8 hours prior to the temperature record; during this time the environmental temperature was almost absolutely constant, and, except in very rare cases, the subject slept the entire night. Finally, as stated above, the temperatures were taken the first thing in the morning, before activity of any kind was engaged in. The conditions thus seemed to be ideal for obtaining true records of the rectal temperature. As with a number of our observations, the records of the rectal temperature under these conditions were not begun until November 11; hence

the rectal temperatures of Squad A prior to diet reduction were not secured.

The rectal temperatures obtained for Squad A throughout the entire series are given in table 21. From this it is seen that the only record of a really abnormal temperature was that for *Kon* on December 9. *Gar*, on November 25, had a slight rise in temperature which, after his return to Springfield, was followed by another rise in temperature due to a cold. The inspection of these figures shows that the temperatures were practically all within so-called "normal" limits. It should be observed, however, that the group averages are not strictly comparable. Thus, on all measurements subsequent to December 9, *Spe* was missing. On January 13 *Tom* was likewise missing, and on January 27, owing to the fact that *Tom* had had an operation for hemorrhoids, the axillary temperature alone could be obtained.

TABLE 21.—*Rectal temperatures during period with reduced diet*[1]—*Squad A.*
[Subjects post-absorptive and in lying position.]

Subject.	Nov. 11.	Nov. 25.	Dec. 9.	Dec. 20.	Jan. 13.	Jan. 27.	Feb. 3.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Bro........	97.6	97.4	97.2	97.0	96.7	97.1	97.6
Can........	97.7	97.6	97.7	98.2	97.7	97.6	97.8
Kon........	97.9	97.9	100.2	97.3	97.9	97.7	99.0
Gar........	96.6	99.0	96.3	96.9	96.8	95.8	96.0
Gul........	97.1	96.5	97.7	97.1	97.1	97.0	97.3
Mon........	98.4	97.8	98.5	98.8	97.7	98.2	98.7
Moy........	98.0	97.1	97.5	97.4	97.2	96.8	97.1
Pea........	97.5	96.8	97.4	97.2	97.1	97.1	96.6
Pec........	98.1	97.9	98.5	98.0	97.2	97.1	97.2
Spe........	97.4	97.5	97.6	....	....	....	....
Tom........	96.8	97.1	97.3	96.7	....	[2]96.3	97.2
Vea........	98.2	97.5	97.9	98.0	97.6	98.0	97.4
Average....	97.6	97.5	97.8	97.5	97.3	97.2	97.4

[1] Observations were made early in the morning after a night in the group respiration chamber. The last preceding meal was the standard supper (700 cals.) served at the restaurant.
[2] Taken in axilla; not included in average.

On the other hand, actual computations show that the changes in temperature of the individuals were so slight that excluding one or two men does not materially alter the general average for the temperature measurement. The average values for the complete series ranged from the maximum of 97.8° F. on December 9 to a minimum of 97.2° F. on January 27.

Under these conditions it is clear that the average rectal temperature of Squad A from November 11 to February 3, inclusive, can not be said to have undergone measurable change. An examination of the data for different individuals shows likewise no tendency for a distinct alteration in temperature, and we must conclude that the

effect of the reduced diet upon these men is without influence upon the rectal temperature taken under the conditions observed in these tests.

It would be conceivable that with Squad A a perceptible fall in temperature might take place in the first month of the diet reduction. This of course would not be shown by our values, as we had no records of the normal temperatures previous to the reduction in food. With Squad B, however, a sufficient number of rectal temperatures were recorded prior to the diet reduction to give a suitable base line. The records for Squad B are given in table 22. Here the situation is complicated by the fact that occasionally the individual members of the squad were changed for reasons beyond our control, but this, we believe, has no effect upon the general averages.

TABLE 22.—*Rectal temperatures of Squad B.*[1]

[Subjects post-absorptive and in lying position.]

Subject.	Normal diet.			Reduced diet.		
	Nov. 18.	Dec. 16.	Jan. 6.	Jan. 14.	Jan. 20.	Jan. 28.
	°F.	°F.	°F.	°F.	°F.	°F.
Fis	97.2	(2)	96.9	96.7	96.9	96.5
Har	98.3	97.7	98.7	97.9	97.7	96.9
How	97.9	97.7	97.6	97.5	97.2	97.3
Ham	97.4	97.5	97.6	97.4	97.2	96.9
Kim	(3)	(3)	98.3	96.6	97.1	97.1
Lon	98.4	98.5	(4)	98.6	97.3	96.6
Sch	(5)	(5)	97.2	97.4	97.5	96.6
Liv	97.9	97.0	97.9	97.7	97.0	97.1
Sne	98.3	97.7	97.0	97.8	97.4	97.1
Tho	98.4	98.5	98.8	97.9	97.3	96.9
Van	97.5	97.2	97.0	97.1	96.9	96.2
Wil	97.3	97.4	97.7	96.7	96.9	96.2
Average	97.9	97.7	97.7	97.4	97.2	96.8

[1] Observations were made early in the morning after a night in the group respiration chamber. The last preceding meal was the standard supper (700 cals.) served at the restaurant
[2] Leo substituted for Fis, Dec. 16; rectal temperature, 97.6° F.
[3] McM substituted for Kim; rectal temperature, Nov. 18, 98.5° F.; Dec. 16, 98.1° F.
[4] McM substituted for Lon, Jan. 6; rectal temperature, 98.1° F.
[5] McD substituted for Sch; rectal temperature, Nov. 18, 98.2° F.; Dec. 16, 97.5° F.

Prior to the diet reduction the values for Squad B on November 18, December 16, and January 6 show averages of 97.9°, 97.7°, and 97.7° F., respectively. In other words, the rectal temperature can be said with this squad of 12 men to be constant. Subsequent to the change in diet there is, in rather striking contrast to the values found with Squad A, a distinct tendency for the rectal temperature to fall. Thus, on January 14, approximately one week after the reduced diet began, the average temperature was 97.4° F., at the end of two weeks, 97.2° F., and at

the end of three weeks, 96.8° F. It is quite clear from an inspection of the individual values that this is a positive reduction in temperature which was not found with Squad A, although the absence of true normal values for the latter squad complicates the comparison. Furthermore, the absolute minimum value of 96.8° F. on the last day (January 28) is perceptibly lower than the average minimum found with Squad A on February 3, that is, 96.8° F. against 97.4° F. The only explanation that one can offer for this difference is the fact that Squad B, during the month of January, was on an extraordinarily reduced diet, containing but approximately 1,400 net calories, or a little more than one-third of the calories in the maintenance diet previous to restriction.

It is conceivable, therefore, that with so low a diet a slight reduction in temperature may have resulted. This is somewhat in conformity with the experience of this Laboratory with the man undergoing prolonged fasting,[1] when it was found that the average rectal temperature throughout the night was somewhat lower at the end of the prolonged fast than at the beginning. This lowering of temperature was likewise observed with this man in the record made at 7 a.m., the temperature being a few tenths of a degree higher at the beginning of the fast than at the end. It would, therefore, appear that with Squad B pronounced undernutrition affected the body temperature slightly, although the fact that so large a reduction in diet (amounting to nearly two-thirds of the previous requirement) had no greater effect upon this important body function is somewhat remarkable. Since the rectal temperatures were so slightly affected, it is not surprising that no appreciable alteration in the mouth temperature could be noted as the experiment progressed.

SKIN TEMPERATURE MEASUREMENTS.

The feeling of cold experienced by nearly every member of the squad, causing discomfort in many instances, led us to believe that there might possibly be a very considerable difference in skin temperature. The fact that there was a distinctly lower heat production suggests a lower skin temperature. Thep ronounced decrease in pulse-rate might also lead one to expect lower skin temperatures. The measurement of skin temperature has been found difficult, but it is believed that the method outlined in an earlier section (page 78) gave an approximate index of the skin temperature which, if not absolutely reliable, should at least permit comparative measurements from week to week. The control observations made with those not on diet also give a suggestion as to whether the surface temperatures of the squad on diet were, on the whole, lower or higher than those of normal individuals. Here, again, the number of control individuals was altogether

[1] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 95.

too small for best deductions. The measurement of skin temperature was admittedly an afterthought. The results are, however, sufficiently extensive to warrant presentation, if the paucity of normals is duly considered. The values obtained for Squads A and B are accordingly given in table 23.

TABLE 23.—*Skin temperatures of Squads A and B during periods of reduced diet.*

Squad A.			
Date and subject.	Temperature of— Right hand.	Left hand.	Forehead.
Jan. 26, 1918:[1]	°C.	°C.	°C.
Bro	25.88	25.36	32.09
Can	32.27	32.16	33.24
Kon	26.44	25.53	32.69
Gar	32.65	31.29	33.28
Gul	32.72	33.52	33.00
Moy	24.62	25.71	32.62
Pea	32.37	32.27	31.53
Pec	25.46	25.08	32.27
Tom	28.57	27.73	33.24
Vea	29.96	29.68	31.81
Average	29.09	28.83	32.58
Controls:			
1	31.39	30.80	34.57
2	31.88	32.72	34.08
3	30.97	29.96	33.91
4	30.45	30.63	33.56
Average	31.17	31.03	34.03
Feb. 2, 1918:[3]			
Bro	34.93	35.40	34.29
Can	33.32	33.10	34.50
Kon	32.67	30.62	34.50
Gar	33.68	34.07	34.79
Gul	33.46	33.60	34.39
Mon	34.43	34.86	34.43
Moy	29.19	31.63	33.89
Pea	31.74	32.78	33.46
Pec	32.38	25.92	33.71
Tom	27.90	26.35	34.50
Vea	28.76	25.56	33.78
Average	32.04	31.26	34.20
Controls:			
2	32.46	33.50	35.08
5	31.99	32.10	33.93
6	33.60	33.93	34.29
7	34.29	34.21	34.29
8	32.99	32.63	33.86
9	33.25	33.21	33.10
Average	33.10	33.26	34.09

Squad B.			
Date and subject.	Temperature of— Right hand.	Left hand.	Forehead.
Jan. 19, 1918:[2]	°C.	°C.	°C.
Fis	29.73	29.76	32.46
Har	30.96	30.30	32.66
How	30.70	32.36	32.86
Ham	31.80	31.83	32.43
Kim	32.36	32.03	34.10
Lon	32.83	31.63	32.93
Sch	31.93	31.10	33.43
Liv	32.20	32.26	32.66
Sne	32.26	32.63	32.23
Tho	32.63	32.93	32.66
Van	28.40	26.73	32.10
Wil	30.33	27.85	31.93
Average	31.34	30.95	32.70
Controls:			
1	29.46	29.63	33.63
2	31.10	30.40	34.23
Average	30.28	30.02	33.93
Jan. 27, 1918:[4]			
Fis	31.36	30.45	34.44
Har	34.44	33.28	34.97
How	32.37	33.09	34.16
Ham	34.53	34.44	34.60
Kim	31.46	31.77	35.00
Lon	33.90	34.44	34.44
Sch	33.84	33.65	34.34
Liv	32.71	33.24	34.28
Sne	33.12	32.65	34.25
Tho	27.81	28.50	33.59
Van	32.52	32.11	34.60
Wil	31.99	31.46	34.47
Average	32.50	32.42	34.43
Controls:			
1	33.50	32.77	35.16
2	33.50	33.56	34.63
5	33.09	33.21	34.16
6	33.56	33.65	34.25
Average	33.41	33.30	34.55

[1] Room temperature, Jan. 26, 22.8° C.
[2] Room temperature, Jan. 19, 23.6° C.
[3] Room temperature, Feb. 2, 25.2° C.
[4] Room temperature, Jan. 27, 27.3° C.

The first series of skin temperature measurements was made with Squad B on January 19, when the men had been two weeks on the reduced diet. The subjects had been sitting in the library taking the group psychological tests for approximately an hour prior to the temperature measurements, and had engaged in no physical exercise. At the end of these group psychological tests the men were instructed to place their hands, palms down, upon the table and remain quiet while the observations on skin temperature were being recorded. The room temperature, as taken by a thermometer suspended at approximately the level of their heads, indicated 23.6° C. on this particular date. The results of the temperature measurements upon the surface of the upper side of the right and left hands and on the forehead are given for all of the men in Squad B, together with the measurements for two individuals on unrestricted diet. Subsequent observations of the temperature of the forehead have shown that this location gives by far the best measurement of the skin temperature, with less fluctuation, than any other part measured.

Measurements were made upon the backs of both the right and left hands to find if the unilateral disturbance suggested in some of the protocols and subjective impressions of some of the men was actually present. An inspection of the values for Squad B on January 19, shows that there is relatively little difference between the temperatures for the two hands. In only three cases (*How*, *Van*, and *Wil*) were there differences greater than 1.5° C. That this difference is not characteristic of these men can be seen from subsequent values found on January 27, on which date the temperatures for both hands were much more nearly constant.

Comparing the values for Squad B on January 19 with those for two normals on the same date, we find that for the right hand the average temperature is for the 12 men 31.34° C., while the record for each of the normals is somewhat less than this. With the left hand the average temperature for Squad B is 30.95° C.; both of the normals show temperatures somewhat lower. These results would indicate that the average temperature of the hands with Squad B was slightly higher than the temperature measurements obtained for the two normals. It should be stated, furthermore, that both normals had been moderately occupied in giving the psychological tests during the previous hour, which involved considerably more exercise than had been taken by Squad B.

The temperature of the forehead ranged with Squad B from 31.93° C. (*Wil*) to 34.1° C. (*Kim*). The average for the 12 men is 32.7° C. The two normals, however, show perceptibly higher forehead temperatures, namely, 33.63° C. and 34.23° C.

Subsequent research has shown the rather striking influence of changes in room temperature upon the temperature of the skin.

The only conclusion that one can fairly deduce from this particular day, therefore, is that the skin temperatures of Squad B, after approximately two weeks of reduced diet, were not greatly unlike those of the two normals with whom they were compared.

On January 26, ten members of Squad A were studied. These men had been on a reduced diet for approximately four months, and the temperature measurements were made under exactly the same conditions as those for the test with Squad B on January 19, namely, in the library immediately after the hour of the group psychological tests. The room temperature was 22.8° C. Considering the measurements on the right and left hands first, we find no pronounced difference between the two hands as measurements differing by over 1.5° C. are found in no instance with any member of the squad. On this particular evening we fortunately had four normals for control, and hence can speak more confidently of the comparison with the normal individuals. The average temperature for the right hand found with ten members of the squad was 29.09° C. With the normals the average was somewhat higher, *i. e.*, 31.17° C. With the left hand similar average figures were obtained, being 28.83° C. for Squad A and 31.03° C. for the normals. The very low values found for a few men of Squad A should be noted, namely, those with *Bro*, *Kon*, *Moy*, *Pec*, *Tom*, and *Vea*, all values very perceptibly lower than the normal values. Thus, though the evidence is strongly against any unilateral temperature condition, there is positive evidence that with certain members of this squad the skin temperature on the backs of the hands was considerably lower than that of normal individuals.

The forehead temperature ranged from a minimum of 31.53° C. with *Pea* to a maximum of 33.28° C. with *Gar*—a very small range. The average, however, for the entire squad, namely, 32.58° C., is perceptibly lower than the average of 34.03° C. for the four controls, thus indicating that with Squad A not only the surface of the hands but likewise the forehead had a measurably lower temperature than was found in the same locations with the control men.

On January 27 a second series of records for Squad B was obtained. By desire of the subjects, the temperature of the room was unusually high, being 27.3° C., but all the men, including the four controls, were subjected to the same temperature for the same length of time. The hand temperatures again indicate close agreement between the right and left hand, with no temperature difference greater than 1.5° C. The average value for the right hand for the squad of 12 men was 32.50° C., while the average for the 4 controls was 33.41° C. With the left hand the average value was 32.42° C. and with the controls 33.30° C. The temperature of the forehead was perceptibly higher than in the earlier observations on January 19, this being due, in all probability, to the higher room temperature on

January 27. With the 12 men the values ranged from 33.59° C. to 35.00° C. The 4 control men gave values averaging 34.55° C., while the average for the 12 men was essentially the same, 34.43° C.

On February 2 the last series of skin-temperature measurements was obtained with Squad A. Here again we find a number of distinctly low measurements for the surface of the hand, these occurring with *Moy*, *Tom*, and *Vea*. With *Pec* the temperature of the left hand was perceptibly lower than that of the right. These readings were very carefully checked several times to determine beyond question this pronounced difference. We are unable to explain it. Personal statements of a member of *Pec's* family to the effect that one side of his body seemed to be much colder than the other might be considered of significance here were it not for the fact that in the study made of this man on January 26, although the surface temperatures of both hands were low, they agreed with each other to within 0.38° C. The average value for the right hand with Squad A on February 2 was 32.04° C., which was perceptibly lower than the average found with 6 controls (33.10° C.). The room temperature on this date was 25.2° C.

The forehead temperatures for Squad A on the same day ranged from a minimum of 33.46° C. to a maximum of 34.79° C., the average value being 34.20° C. As a matter of fact, this average value is slightly higher than the average forehead temperature of 34.09° C. found for the 6 controls.

Giving full recognition to the paucity of normals and the difficulty of obtaining accurate skin temperatures, we find that an analysis of the foregoing data does not indicate uniformly lower surface temperatures for most of the men. With certain members of the two squads, the skin temperature as measured on the back of the hands was definitely lower than the normal values. In one or two instances, at least, low temperatures for the surface of the hand were observed with considerable regularity, these men being those who apparently suffered most from cold hands. Thus *Vea*, of Squad A, frequently complained of cold hands, and on the two days when his surface temperature was measured values lower than normal were found. On January 26 his values were higher than the average for the whole group, but on February 2 they were lower than the values obtained for any other man in Squad A except for the right-hand temperature of *Tom*. With *Bro* very low values were found on January 26, while values slightly higher than normal were found on February 2. With *Tom* a low value was found for both days. *Pec*, with the single exception of the right-hand measurement on February 2, also gave a low record. With the forehead temperatures the variations from normal show no material uniformity.

RELATION OF BODY TEMPERATURE TO MUSCULAR ACTIVITY.

Although considerable emphasis in this research was laid upon the reaction of the pulse-rate to muscular activity, which was studied both

in the Nutrition Laboratory and by Professor Johnson in Springfield, unfortunately our temperature measurements were not made for the purpose of determining the reaction of the temperature regulating function to muscular work. *Pea* was captain of the cross-country team, and on several occasions ran a strenuous race. On November 28 he ran a race of 6¾ miles according to the pedometer record. It was impracticable to measure his rectal body temperature under these conditions, but the mouth temperatures are perhaps not without some interest. At 9^h30^m a. m. after breakfast, when he was lying down, the mouth temperature was 98.6° F. After a run of 54 minutes of approximately 7 miles, and while the subject was lying on the bed, the mouth temperature at 11^h18^m a. m. was 97.4° F. The fact that this subject had been running a race in the open air, with probably more or less mouth breathing, makes these records of relatively little value. The difficulties in obtaining accurate records of the mouth temperature, especially after long races, have been carefully pointed out by Dr. Blake in his observations on Marathon runners.[1] It is more than probable, however, that there was no true increase in temperature as a result of this activity, for this fall of 1.2° F. is not unlike that recorded by Blake and his co-workers in the case of the Marathon runners.

CONCLUSIONS REGARDING EFFECT OF DIET ON BODY TEMPERATURE.

Practically all that can be said regarding these records of body temperature is that the reduced diet did not, save in the case of Squad B, produce any noticeable alteration from the ordinary temperature control exhibited by normal individuals. The febrile temperature of *Spe* has been a matter of very considerable perplexity. On December 9, at 6 a. m., in the respiration chamber in Boston, this subject gave a rectal temperature of 97.6° F. On December 12 at 5^h45^m a. m., prior to the gaseous-metabolism experiment, he had a mouth temperature of 99.6° F. On December 13 records of the mouth temperature were taken very frequently. In the morning it was 100.5° F.; later in the afternoon the attending physician recorded it as 102° F.; at 6^h30^m p. m., 102.5° F.; at 7 a. m., December 14, 102.2° F.; at 6 p. m., December 14, 104.2° F.; and in the early morning of December 15, 102.8° F. *Spe* then left Springfield for his home. The body-temperature record in the subsequent course of the illness is given in figure 87 on page 363. The variations in the temperature curve of typhoid patients are altogether too wide to allow any deductions as to whether this case of suspected typhoid showed usual values or not. It is clear, however, that no extraordinarily high or low temperature measurements were found even in this case of infection, and that the important temperature-regulating function of the body is capable of

[1] Blake and Larrabee, Boston Med. and Surg. Journ., 1903, **148**, p. 195.

withstanding very material alterations in the diet without noticeable disturbance.

In the recent study made by Loewy and Zuntz,[1] the latter found no change in his body temperature at the end of his experiments on low diet, the values obtained in 1916 being no lower than those recorded prior to the war. No temperature measurements for Loewy are reported.

DIFFICULTIES IN TEMPERATURE REGULATION AS INDICATED BY CLOTHING.

A noticeable feature of the experiment, which became evident about the middle of November and was more pronounced in the latter part of the research, was the extreme sensitivity of the subjects to cold.[2] The winter of 1917–18 was unusually severe, which may, in small part, have accounted for this increased sensitivity, but the evidence seems to be clear that the men on diet were actually more sensitive to cold than their college mates living under normal conditions.

This increased sensitivity to cold manifested itself in several ways:

(1) Nearly all of the men wore heavier underclothing than usual and were inclined to wear more overclothing.

(2) The bed clothing was frequently very noticeably increased.

(3) The men were also inclined to gather about the steam radiators whenever possible.

(4) They avoided swimming in the natatorium, although the water felt comfortably warm to their college mates.

As early as November 4, 1917, several of the men, especially *Pec*, *Can*, and *Pea*, complained of being cold during the morning respiration experiments. Although the temperature of the room was normal, they asked for additional blankets, and *Pea* had changed to heavy winter underwear on the day previous on account of the cold. After the excess diet on the uncontrolled Sundays, it was not infrequently reported by the subjects that they felt much warmer and more comfortable than on the days when the diet was restricted.

December 6, *Can*, *Tom*, and *Pec* complained of the cold hands of the assistant who was taking the pulse-rate. At the Nutrition Laboratory, although the halls were sufficiently warm for persons wearing ordinary clothing, it was noted that when the later series of profile photographs was taken with Squad A, gooseflesh appeared almost immediately when the subject removed his bath wrap. This did not occur with Squad B. On reaching the Laboratory when they came to Boston, the members of Squad A would gather around the radiators and apparently take this time to get warm.

On February 2 (the experiment ended on February 3) each member of the squad was questioned particularly with regard to clothing worn during the experiment. Their comments follow:

Pea reported that during his 3 years in college he had always worn light underwear through the winter and did not feel the cold. During the

[1] Loewy and Zuntz, Berl. klin. Wochenschr., 1916, **53**, p. 829.

[2] Increased sensitivity to cold was experienced by the fasting subject. (Benedict, Carnegie Inst. Wash., Pub. No. 203, 1915, p. 194.)

winter of 1917–18 he had to wear heavy all-wool underwear. He noticed his feet and hands were particularly cold. His roommate, who was not a member of Squad A, wore light underwear as usual.

Gar had worn light underwear during the winter for 4 or 5 years. During that time he had not noticed the cold particularly. During the winter of 1917–18 he wore medium-weight union suits, half wool and half cotton, with full-length sleeves and ankle-length legs. His roommate, who was not on the squad, wore no heavier underwear than usual.

Gul stated that he had worn no underwear since the experiment began. He found it especially difficult to reduce his weight 10 per cent, and believed that if he wore no underwear the radiation of heat would be more rapid. Usually he wore light underwear in the summer and heavy underwear in the winter. During the intense cold of 1917–18 his shins felt very cold when the wind came in between his socks and trousers. When he first came to Massachusetts from North Dakota, a few years before, he did not feel the cold, because the winters in North Dakota are more severe than in Massachusetts. He thought he had not suffered from the cold more during the experiment than in the preceding winter. He wore underwear during the previous winter and had had two colds, the cause for which was not evident. During the winter of 1917–18 he had had no colds. It is a surprising fact that although the other subjects showed great sensitiveness to cold, this man was able to wear absolutely no underwear during the unusually severe winter and with a low diet. This is in striking contrast to the experience of practically all of the other members of the squad.

Vea, for the previous 4 years, had worn light underwear throughout the whole winter. During the winter of 1917–18 he wore cotton and light-weight woolen underwear, with long sleeves and legs of ankle length. For his walks outdoors, he put on woolen socks. During the last two weeks of the experiment he wore a basket-ball shirt under his regular shirt, in addition to the underclothes. The overcoat worn during the winter was lighter than usual.

Can had usually worn two-piece light-weight underclothes, but during the experiment he wore a knitted sweater and heavier drawers and socks than ordinarily. At times he put extra blankets on the bed to keep warm at night.

Tom, although not actually suffering from the cold, had felt cold and found his tendency was to stay indoors more. He slept in his bath-robe many times and kept moving when out of doors. It was his usual habit to wear the same weight of clothing throughout the year, with the exception of an overcoat in winter. During the experiment he wore no heavier underclothing or socks than usual. His chief difficulty was in keeping warm at night. Although he used an extra pair of blankets, besides his bath-robe, he was unable to keep warm in bed.

Pec reported special difficulty in keeping warm. On going to bed he could not get to sleep for half an hour on account of the cold. He usually wore a union suit of medium weight, but during the winter of 1917–18 he wore the best and heaviest woolen underwear that he could buy. He also wore a very heavy sweater every day in addition to his regular clothing while in the class room and the heaviest woolen socks that he could purchase.

Moy dressed more warmly than usual. For the previous 5 years he had worn light underwear throughout the winter. In November, when the weather became colder, he felt cold and put on union suits, knee-length, with short sleeves and of medium weight, but not all wool; no heavier socks were used. In the extreme cold weather he wore a sleeveless basket-ball sweater over his underclothes a part of the time. He also put more blankets on his bed. His overcoat was heavier than that worn the preceding year.

Kon reported that he suffered from cold. He usually wore light weight underwear, but about the middle of November began to wear heavy union suits, with long sleeves and legs of ankle length, about two-thirds woolen. He also wore heavy woolen socks and a medium-weight overcoat.

Mon suffered from cold, also. He usually wore heavy cotton underclothes and stockings, but in 1917–18 found it necessary to wear wool during the winter and much heavier woolen stockings. Part of the time he wore a jersey sweater and a heavier overcoat than usual, with more blankets at night.

Bro wore, ordinarily, a regulation gymnasium suit as underwear, *i. e.*, a jersey and running costume. During the cold weather of 1917–18 he wore a two-piece fleece-lined suit, but not all wool. This was of medium weight, with long sleeves and legs of ankle length. An extra sweater was worn in gymnasium work. Additional blankets were used at night, but he found it difficult to keep warm. He did not open his window so wide as usual.

The experiment ended for Squad B on January 28 and for Squad A on February 3. On February 8 the men of both squads were interviewed. They showed great uniformity of experience in regard to feeling cold during the period of reduced diet. In general, the members of Squad B did not change to heavier underclothing, and only one or two mentioned heavier outer clothing. The comments of the men, which are given here in detail, show that the contrast between the diet condition and the subsequent period of uncontrolled eating is definite, even though at the time of the interviews but a few days had elapsed since the close of the experiment.

SQUAD A.

Bro had not changed the weight of clothing, but considered doing so mmediately, as he did not feel the cold so much as during the experiment.

Can said cold was not felt so keenly as during the experiment. No change in clothing, except for removal of sweater a part of the time. Much more comfortable than when on low diet; sometimes a little too warm; no change in bedding.

Kon had no doubt as to there being a great difference regarding his sensitiveness to cold; wearing the same clothing.

Gar had put on light silk stockings, but still wore long underclothing. He had not felt the cold so much since returning to full diet, but the weather had not been so cold.

Gul felt warmer than when on low diet. Had not begun to wear underclothes again except a 6-ounce jersey. Intended to put on underclothes the next day.

Mon did not feel cold on full diet. No change in clothing or bedding.

Moy did not notice cold so much as when on low diet; no change in clothing or bedding; sometimes felt too warm.

Pea had taken off flannel drawers and flannel shirt and wearing only a light weight cotton union suit. No change in bedding, but weather not so cold; windows open as usual.

Tom did not mind the cold so much and found that he was warmer in bed than when on the diet. Had taken off two pairs of blankets even during a recent period of cold weather.

Vea very sure that the cold was not felt so keenly as during the experiment. No change in clothing or bedding.

SQUAD B.

Fis, while on low diet, wore the same clothing as usual, with heavy underwear, but was more sensitive to the cold than ordinarily. Endured the cold better after the experiment was over.

Har, during low diet, wore a sweater under his coat most of the time, particularly when out of doors. Felt the cold considerably, even with this extra clothing. After the experiment was over he was not cold and did not wear the sweater.

How said that since the experiment he did not notice the cold, this being the greatest difference between the low-diet period and full diet. No change in clothing or bedding. His room was warm, steam-heated. During low diet, felt the cold keenly, but did not change clothing at all. At a dance during the diet period, he was surprised that he did not perspire as usual.

Ham did not notice the cold when on low diet. Had worn the same weight of clothing all the time.

Kim felt the cold during the low diet but wore clothing as usual; more bed clothing at night, and had continued to use it, but did not feel the cold so much.

Lon had not noticed the sensation of cold so much since the end of the experiment. Wore heavier clothes during the low-diet period, including a regular woolen sweat-shirt over his undershirt, but on full diet found it too heavy. He wore woolen socks during the low-diet period and for three days after the experiment.

Sch, during the diet period, could not perspire; felt the cold keenly in the hands and feet only. On subsequent full diet did not feel the cold. Was sure that this was not due to change in weather, but thought he could endure colder weather with full diet. No change in weight of clothing.

Tho felt the cold very much when on the low diet; sometimes wore an extra sweater during experiment; otherwise no change in clothing.

Van, when on low diet, was cold, required much exercise to warm up, and could not induce perspiration. After full diet was resumed was not cold, required only a little exercise to warm up, and perspired easily. "During this cold weather, I naturally feel the cold, but there is a difference between the way it feels now and when on the diet."

All of the men in Squad A showed a marked disinclination to swim in the natatorium in Springfield as the experiment continued; a number of them found it so uncomfortable that the instructor was obliged to excuse them. On the day that the series of motion pictures was taken, February 1, 1918, the men were very much opposed to swimming until it was found that the water was unusually warm. Some of the men regularly instructed classes in swimming; in the latter part of the experiment these men did not go into the water at all, but instructed from the platform. After the return to the regular diet the subjects entered into the swimming with much enjoyment. This reluctance to go in swimming was not shown by the men in Squad B, even during the third week of the diet restriction; at least they made no comments on it.

During the endurance test, when the subjects held their arms extended horizontally for nearly an hour, it was noted that the hands became very blue, and several of the men reported that they suffered

more from cold hands than from the strain of holding out their arms. On this particular day the gymnasium was unheated and the air particularly cold.

It was also observed that as the experiment continued the men were inclined to take more and more bed clothing into the group respiration chamber for the biweekly night experiments. Frequently the men would use not only their bath robes, but also their overcoats, notwithstanding the fact that the temperature of the chamber did not alter materially throughout the entire experiment. The lowest temperature recorded inside the group respiration chamber at night was 18.5° C. on November 24–25. As a matter of fact, one of the highest temperatures (22.9° C.) was noted the night of January 12–13, when the men were using an excessive amount of bed-covering. The temperature of the air in the chamber remained for the most part very close to 20° C., the total range being not more than 4° C. Since practically all of the men slept at college with their windows more or less open, the temperature of 20° C. in the respiration chamber must, in practically all instances, have been considerably higher than that to which they were regularly accustomed when sleeping. On the other hand, the bed clothing supplied inside the respiration chamber was somewhat less than the covering ordinarily used by the subjects, being that which was considered sufficient in a room at 20° C. for the average person on an ordinary diet.

Evidently there was a distinct tendency with all of these men to be not merely discommoded, but to suffer from the cold as the diet restriction proceeded. If heavier underwear and clothes had been provided prior to the lowering of the weight level it is probable that considerable discomfort might have been avoided. Although there was less heat loss than usual, the sensation of cold in the body was very materially increased. It would thus appear that the process of weight reduction necessarily demands increased clothing for insulation to retard in so far as possible the loss of heat.

The two subjects, *Pec* and *Gul*, give a striking illustration of the extremes in temperature regulation. Although the oldest subject (44 years), *Pec* was very active. He found it almost impossible to keep warm, even with an excess amount of clothing. On the other hand, *Gul*, in spite of the very severe winter, wore no underclothing in the effort to keep down his weight. In other words, he preferred to eat more and to increase radiation by wearing less clothing. It is obvious, of course, that his line of reasoning was not strictly scientific, but it was noted by all of us that *Gul* was a particularly active individual. On the days when the series of motion pictures was taken the other members of the squad gathered around a radiator and the motion-picture operator was cold and inclined to wear an overcoat, but *Gul* ran around in the unheated gymnasium with nothing on but a swimming jockey strap.

DIETS.

In any plan to provide a pronounced reduction in diet it is important to emphasize the character of the foods eaten as well as the amount of reduction. It should be stated at the outset that we hold no thesis for any particular types of food, dietetic peculiarities, or régime. Consequently we believed that the most logical method of studying this problem was to give the men, so far as the character of food was concerned, as great a variety as they would normally receive were they not on diet. Throughout the entire test, therefore, with but very few exceptions, the subjects received regular college mess-hall food. The exceptions were the substitution of grape or apple jelly for butter during certain periods of excessive reduction, and the addition of rather considerable amounts of spinach and bulky food materials that would not commonly be received in the diet. The food was well prepared and served at a special table, but undoubtedly the presence of others consuming liberal amounts of food was disturbing psychologically. The members of the squad frequently indicated that this was a true disturbance.

Since with Squad B the diet restriction amounted to practically two-thirds of the normal intake, that is, the normal intake of approximately 4,000 calories was reduced to approximately 1,500 calories, it became necessary to be sure that no vital food accessories or none of the unidentified dietary factors were omitted. Typical menus covering several days were therefore submitted to Dr. E. V. McCollum, of the Johns Hopkins University, who was kind enough to inspect them and reported that, in his judgment, there was no deficiency in unidentified dietary factors. One difficulty arose in that this reduced diet had a tendency to produce constipation in many cases. This was counteracted by a rather liberal use of bran. At first, admittedly too liberal use was made of the bran until it was realized that an appreciable proportion of the total daily calories was being supplied by this material. Subsequently the bran was used in moderation by practically all of the subjects. In addition, bran biscuits, bran muffins, and some patent bran preparations were used, which made it possible to control the constipation without much difficulty.

At the beginning of the test the Woods Hall dietary included butter; this was later replaced with nut margarine; finally, to reduce the caloric intake and still provide something to eat with bread, the subjects were given jelly as a substitute.

Since we had no predilection for either a high or low protein diet, we gave no attention to the nitrogen intake, at least at the beginning, but simply curtailed the caloric intake in general by serving one-half to one-third of the regular portions. Obviously this procedure automatically resulted in a curtailment of the nitrogen intake. But the fact should be emphasized that these diets were, so far as character is

concerned, changed but little from the ordinary diet. No special factors were missing and our subjects were served food exactly like that served the other college men, except that they were given smaller portions.

The quantities of food served were, in all instances, much smaller than the normal pre-diet food consumption. The total nitrogen and total energy available for the individual subjects are recorded in various tables in other sections of this book; special reference to these

TABLE 24.—*Typical day's diet during period of maintenance of body-weight. Squad A.*

Kind of food (Dec. 12, 1917).	Amount.	Nitrogen.	Energy.
Breakfast:	*gms.*	*gms.*	*cals.*
Bran muffins	75		
Milk (topped)	350	[1]2.75	[1]485
Prunes	30		
Bran	14	.31	58
Sugar	15	....	59
Butter	10	.02	76
Shredded wheat	58	.99	233
Total	....	4.07	911
Dinner:			
Beefsteak	50		
Potato	153		
Tomato	50	[1]4.41	[1]653
Gravy	37		
Bran muffins	100		
Cornstarch pudding	78		
Jelly (currant)	10	....	27
Total	....	4.41	680
Supper:			
Bran muffins	80		
Milk (topped)	233		
Toast	40		
Chipped beef	20	[1]4.35	[1]892
Cream sauce	84		
Potato (fried)	110		
Raspberry preserve	42		
Cookies	23		
Butter	10	.02	76
Total	....	4.37	968
Total for day	....	12.85	2559

[1] Determined; all other values computed.

will not be made until these tables are discussed. Examples of characteristic diets, with amounts served, are, however, of interest here, and we give in table 24 an illustration of a typical day's ration (December 12, 1917) for Squad A during a period of approximate weight maintenance. As will be seen, a large proportion of the diet was

included in the composite samples, as outlined on page 68, and such staples as bran, sugar, shredded wheat biscuit, and butter were not analyzed. The total nitrogen for the day was 12.85 grams and the total energy 2,559 calories. These values represent an average for the 12 men. Individual variations, of course, were somewhat wide. The energy in this table represents the actual heat of combustion, *i. e.*, the gross calories. The menu is given primarily as an indication of the character and amounts of the foods taken by the subjects during the period of approximate weight maintenance.

A few standard meals were regularly used throughout the entire series of tests. Thus, on the biweekly trips to Boston, the men had a standard supper at a local restaurant. This was given throughout the entire winter with but slight changes; repeated samplings of the supper showed practically uniform values for both nitrogen and heat of combustion. These are shown in table 25. The meal was

TABLE 25.—*Standard restaurant supper.*[1]

Kind and amount of food.	Nitrogen.	Energy.
	gms.	*cals.*
1 fried egg 2 pieces bacon (about 15 gms.) 1 boiled potato (medium size; about 115 gms.) 1 dish cooked spinach (113 gms.) Apple pie (4¼ oz. or 120 gms.) ½ orange (about 80 gms..)	[2]2.36	[2]631
1 pat butter (about 10 gms.)	.02	76
Total	2.38	707
No drink except water.		
Vinegar on table for spinach, if desired. No sugar or oil.		

[1] Lettuce was served instead of spinach until December 15. Squad A was given very weak tea with slice of lemon and 7 to 12 grams sugar beginning with December 19. On January 26 the amount of bacon was changed to 1 piece (about 8 grams).

[2] Determined in composite sample.

especially relished by the men, who frequently spoke of it on arriving at the Laboratory. It has special significance as an indication of the character and amount of the food material eaten by each member of both Squads A and B on the evenings prior to the psychological tests.

Similarly on Sunday morning, at the conclusion of the all-night respiration experiments, and just prior to the psychological observations, a standard breakfast was provided at the Nutrition Laboratory. This remained practically uniform throughout the entire period of observation. The menu for this meal is given in table 26. The total amount of nitrogen supplied in this case was 3.55 grams and the total energy 640 calories.

On a certain number of occasions the subjects came to Boston early enough in the day to take a dinner at the restaurant. No major

TABLE 26.—*Standard laboratory breakfast.*

Kind and amount of food.	Nitrogen.	Energy.
	gms.	*cals.*
1 roll (36 gms.) .... ½ banana (50 gms.) .... 1 pint topped milk .... 1 shredded wheat biscuit (28 gms.) .. Jelly (25 gms.) .... Bran (15 gms.) .... Sugar (10 gms)	[1]3.55	[1]640

[1] Computed.

changes were made in this meal during the experimental period, although there were some substitutions owing to the differences in the regular bill of fare available on particular days, and some changes in the total amounts of nitrogen and energy. The menu is given in table 27. The footnotes to this table indicate the character of the changes made on the different days.

TABLE 27.—*Standard restaurant dinner.*[1]

Kind and amount of food.	Nitrogen.	Energy.
	gms.	*cals.*
1 oz. roast lamb, free of fat (28 gms.) 1 boiled potato (about 150 gms.) .... 1 ladleful gravy .... ½ slice bread, white (12.5 gms.) ..... Squash pie (4 oz. or 113 gms.) ..... ½ orange (about 80 gms.)	[2]3.48	[2]546
1 pat butter (about 10 gms.)	.02	76
Total	3.50	622
No drink except water.		

[1] Roast beef (large slice) was served instead of lamb on Nov. 10 and Nov. 24, a smaller potato (about 75 gms.) and a serving of cranberry jelly instead of butter, but of about the same size. On December 8 the roast beef was decreased to about 1 oz., the potato was increased to about 125 gms., and butter was served instead of jelly.

[2] Determined in composite sample.

On Sunday nights in Springfield it was the custom of the college for the men to separate more or less, and no regular evening meal was served. Beginning October 7, the men were assigned small lunches, which consisted at first of a cake of sweet chocolate, with some form of bran. Later the chocolate was omitted and fruit substituted or served alone. The Sunday night suppers, with their nitrogen and energy content, chiefly computed, are given in detail in table 28. Usually, particularly when fruit and bran muffins were given, they were included for analysis in the sample of the noon meal. With the bran preparations and chocolate, analyses of the individual materials

TABLE 28.—*Sunday suppers at Springfield.*

Squad and date.	Kind of food.	Amount.	Nitrogen.	Energy.
Squad A:		*gms.*	*gms.*	*cals.*
Oct. 7, 1917....	Braneta..........................	31	0.48	129
	Baker's chocolate, sweet, 5-cent cake..	58	.33	322
	Total....................	....	0.81	451
Oct. 21, 1917...	Braneta..........................	27	.42	113
	Baker's chocolate, sweet, 5-cent cake..	58	.33	322
	Total....................	....	.75	435
Nov. 4, 1917...	Braneta..........................	32	.50	134
	Baker's chocolate, sweet, 5-cent cake..	58	.33	322
	Total....................	....	.83	456
Nov. 18, 1917...	Bran muffins......................	50	.49	118
	Graham crackers..................	42	.67	187
	Baker's chocolate, sweet............	29	.16	161
	Total....................	....	1.32	466
Dec. 16, 1917...	Apple, as purchased...............	250	0.13	121
Jan. 20, 1918...	Bran muffins......................	90	1.03	245
	Apple, as purchased...............	125	.06	61
	Total....................	....	1.09	306
Jan. 27, 1918...	Apple, as purchased...............	200	0.10	97
Squad B:				
Jan. 20, 1918...	Bran muffins......................	90	1.03	245
	Apple, as purchased...............	225	.11	109
	Total....................	....	1.14	354

made it possible to compute the nitrogen and energy as indicated in the table.

Squad B, which was put upon an extremely low ration during the month of January, received reasonably uniform calories throughout the entire period, averaging 1,375 net calories. A typical day's ration, that for January 25, is given in table 29. A composite sample was made of all three meals, excluding certain of the staples, such as jelly, sugar, orange, and bran. The nitrogen and energy, as computed from standard analyses, are likewise included in table 29 to show the general distribution among the various food materials and in the three meals. The actual determinations for the total nitrogen intake and total gross calories in the composite sample are given at the bottom of the table. These, with the computed nitrogen and energy in the staple foods, give a total for the day of 8.78 grams nitrogen and 1,555 gross calories.

TABLE 29.—*Typical day's ration during period of reduced diet, Squad B (Jan. 25, 1918).*

Kind of food.	Amount.	Nitrogen.	Energy.
Breakfast:	*gms.*	*gms.*	*cals.*
Orange (1)	160	0.21	86
Shredded wheat	30	.51	121
Milk (topped)	233	1.04	102
Toast	25	.38	78
Sugar	9	....	36
Jelly (grape)	10	....	26
Bran	12	.32	50
Total (computed)	....	2.46	499
Dinner:			
Soup	70	.41	19
Fish	40	1.16	87
Potato (riced)	70	.28	70
White sauce	37	.17	54
Corn (canned)	44	.20	46
Bread ("war bran bread")	50	.95	175
Ice cream	67	.29	140
Jelly (grape)	10	....	26
Total (computed)	....	3.46	617
Supper:			
Potato (fried)	57	.23	102
Meat (roast beef)	30	1.07	116
Bread ("war bran bread")	45	.85	157
Cocoa	125	.46	89
Peach (canned)	41	.05	20
Chocolate cookies	16	.18	69
Jelly (grape)	10	....	26
Total (computed)	....	2.84	579
Total for day (computed).	....	8.76	1,695
In composite sample for day (determined)	....	8.25	1,306
Extras not in sample (computed):			
Orange	160	.21	86
Jelly	30	....	77
Sugar	9	....	36
Bran	12	.32	50
Total for day	....	8.78	1,555

PROPORTIONS OF NUTRIENTS IN THE DIET.

As previously stated, no attempt was made to secure either high or low protein in the diet, the adjustment being made wholly upon the caloric content. The lowering of the energy automatically resulted in a lowering of the protein. The actual protein intake can be obtained for practically any day for any one of the subjects by multiplying the nitrogen in the food (see tables 46 to 70) by the standard factor 6.25. It was impossible to complicate the entire research by an attempt to apportion the non-protein energy between fat and carbohydrate.

A careful inspection showed there was no deficiency of either; in other words, there was no excessive fat or excessive carbohydrate. To obtain an approximate estimate of the relative proportion of fat and carbohydrate in the food, certain composite samples were analyzed, the fat being determined by ether extraction and the total carbohydrates by hydrolysis. The results of these analyses are given in table 30. These were not used for computing the total energy of the

TABLE 30.—*Fats and carbohydrates determined in typical composite samples of food.*

Squad and date.	Sample.	Weight of partially dried sample.	Total fats.	Total carbohydrates.
		gms.	*gms.*	*gms.*
Squad A, reduced diet, Oct. 9, 1917..	*a*	362	44.1	178.7
	b	357	47.8	171.5
Average....................	....	....	46.0	175.1
Squad A, reduced diet, Dec. 5, 1917..	*a*	351	33.7	167.4
	b	340	34.8	158.2
Average....................	....	....	34.3	162.8
Normal diet, group of 12 men, Nov. 20, 1917........................	*a*	661	83.1	340.8
	b	660	95.6	342.2
Average....................	....	....	89.4	341.5

day, for to these materials should be added the nitrogen and energy of certain staples, such as sugar, bran, jelly, butter, etc. They serve to show, however, that the diets were by no means deficient in fat. The results given for November 20, 1917, are for a normal group with uncontrolled diet. Roughly speaking, the fat in the diet on November 20 is twice that in the other two samples analyzed and the carbohydrates are increased by approximately the same percentage.

EXTRA FOODS.

In the case of the 12 normal men studied in the experiment of November 20 to 24, inclusive, extra foods were eaten away from the table (see table 32), but with Squads A and B no foods were consumed away from the table on the days with controlled diet. On the other hand, a regrettable feature in the study with Squad A was the desire of most of the men to chew gum excessively. For a few days gum-chewing was allowed *ad libitum*, but no record was made of the amounts used. Later it was recognized that an appreciable amount of energy was supplied by soluble carbohydrates in the gum. Thereafter records of the gum used were made for all of the men in both squads during the diet restriction.

A typical weekly gum record for Squads A and B is given in table 31. This shows that most of the men in both squads used rather large amounts of gum, although it so happens that one member of each squad

TABLE 31.—*Typical week's record of gum-chewing of Squads A and B.*

Squad A,[1] Dec. 12–18, 1917 (inclusive).		Squad B, Jan. 15–21, 1918 (inclusive).	
Subject.	No. of sticks.	Subject.	No. of sticks.
Bro......	4	Fis........	13
Can......	10	Har[2]......	0
Kon......	9	How......	15
Gar......	14	Ham......	14
Gul......	18	Kim......	14
Mon......	14	Lon.......	14
Moy......	12	Sch.......	18
Pea......	17	Liv.......	9
Pec[3]......	0	Sne.......	14
Tom......	14	Tho.......	14
Vea......	14	Van.......	14
		Wil.......	14

[1] Subject *Spe* left the squad during the week here given. He had on the average 2 sticks of gum per day until November 8, after which his records repeatedly show days with no gum.

[2] *Har* chewed but little gum; during January he had gum on only 6 days, with an average of about 2 sticks per day.

[3] *Pec* usually chewed no gum. On occasional days throughout the series he chewed 2 or 3 sticks; on two days in October he chewed 5 sticks per day.

took practically none (*Pec* in Squad A and *Har* in Squad B). The weekly gum record of a group of 12 men with uncontrolled diet was studied on November 20 to 24, the number of men studied apparently being sufficient to give a fair indication of the use of gum by the college body. Two or three of the men in this group were also members of Squad B. The amount of gum used was small as compared with the amounts given for Squads A and B in table 31, the total number of sticks per day for the 12 men for 5 consecutive days being 7, 7, 8, 0, and 5. These small amounts led to an inspection of the gum record for all the members of Squad A, which revealed an increased use of gum as the restriction in diet continued. By analysis it was found that each stick of gum represents approximately 2 grams of soluble carbohydrates, or 8 calories. The use of gum must therefore be considered in a careful calculation of the energy in the diet.

This intake of energy from the chewing of gum serves as another illustration of the subtle manner in which unidentified calories may creep into a supposedly controlled diet.[1] The amount of extra foods consumed by the normal group of 12 men in the period of November 20 to 24 was very large, representing on the average not far from 5 per

[1] Benedict and Benedict, Boston Med. and Surg. Journ., 1918, **179**, p. 153.

cent of the total nitrogen and, of still more significance, 10 per cent of the total calories ingested. (See table 32.)

Table 32.—*Computed nitrogen and energy in food of normal group of 12 men, Nov. 20 to 24, 1917.*

[Values per man per day.]

Date.	In total food including "extras."		In "extras."	
	Nitrogen.	Energy (gross).	Nitrogen.	Energy (gross.)
	gms.	*cals.*	*gms.*	*cals.*
Nov. 20.....	20.80	4,246	1.52	536
21.....	17.06	4,174	.64	417
22.....	17.95	3,961	.90	316
23.....	17.08	4,023	.60	362
24.....	19.41	4,117	1.02	414
Average..	18.46	4,104	0.94	409

UNCONTROLLED MEALS.

Ideally, an experiment such as this should be carried out with every meal controlled. Practically, although we enjoyed the fullest cooperation of the subjects, it became psychologically impossible to control every meal throughout the entire period of 4 months. Consequently, the men were allowed an uncontrolled diet on the Sundays following the biweekly experiment in Boston. They were specifically cautioned, however, to control the diet so far as possible and to make reports of what they ate. At the Thanksgiving recess for a few days it again became necessary to allow the men uncontrolled diet. Again, during the Christmas vacation, a number of the men went to their homes. For several of them this was possibly a farewell visit, as they were going into active war service; under the circumstances we could not urge them to remain in Springfield for the holidays. They were, however, requested to curtail the diet in so far as they could and to endeavor to return to Springfield as nearly as possible with no change in body-weight. More than this we could not conscientiously do. Subsequent inspection of the data returned by these men as the record for the uncontrolled meals on Sundays made us regret extremely that we did not urge more strongly the desirability of complete control throughout every meal, even at the sacrifice of shortening the entire experiment. Some of the Sunday meals were excessive in amount in both nitrogen and calorie content. It would seem almost incredible that such quantities of food could be eaten without extreme discomfort. In fact, a certain amount of discomfort was produced in a majority of cases.

An extreme case of an uncontrolled Sunday diet is that given in table 33 for *Gul* on January 13. On this day the food ingestion began with the standard laboratory breakfast, followed by several light lunches

TABLE 33.—*Sunday diet (uncontrolled), typical of large intake of nitrogen and energy—Gul, Squad A, Jan. 13, 1918.*

Kind of food.	Nitrogen.[1]	Energy.[1]	Kind of food.	Nitrogen.[1]	Energy.[1]
Breakfast.	*gms.*	*cals.*	*Dinner.*	*gms.*	*cals.*
At laboratory:			Soup, tomato	0.65	97
Roll	0.53	104	Beefsteak (4 pieces)	14.92	676
Banana (one-half)	.11	50	Potato (2 helpings)	.84	230
Milk, topped (1 pint)	2.07	203	Gravy (2 helpings)	.35	65
Shredded wheat	.48	113	Coffee	.16	62
Jelly	....	67	Ice cream (2 dishes)	1.08	523
Sugar	....	40			
At restaurant:			*Supper.*		
Griddle cakes (2 orders)	2.80	861	Toast (3 pieces)	.92	188
Coffee	.16	62	Coffee (2 cups)	.32	124
			Custard pie	1.17	330
Extras—			Cookies (four)	.67	260
Apple	.09	85	Peas	.49	52
Chocolates (½ lb.)	....	892	Butter (1 pat)	.02	80
Bran	.64	100			
Epsom salts	....	....	Total for day	28.47	5,264

[1] Computed.

after the subject left the Laboratory, with a very large dinner and a large supper, although the exact distinction between dinner and supper is somewhat in doubt. Suffice it to say that *Gul* on this day obtained over 28 grams of nitrogen and 5,264 gross calories of energy.

Although we had to base our computations not only for this subject but for all others upon their personal statements, with no weighings and only approximate estimates as to the composition of the cooked foods, we have computed the probable nitrogen and energy intake of the subjects on the uncontrolled Sundays, including, also, the laboratory breakfast. This is of such general interest, especially in subsequent discussion, that it is deemed important to present it in considerable detail in table 34. In general the amount of food eaten was very large, the caloric intake being on the average not much different from that obtained for the normal group of 12 men from the Y. M. C. A. College studied from November 20 to 24. (See table 32.) The average nitrogen intake on these uncontrolled Sundays was 16.62 grams nitrogen, and the average gross energy was 3,994 calories. Comparing these amounts with the actual food consumption at or about this period, it can be seen that the excess in the nitrogen and energy intake was large during the break in training on these days.

This excess food has been for us a perplexing problem, the sudden ingestion of a large amount of nitrogen interfering considerably in the intelligent interpretation of our results. The sudden ingestion of a large amount of energy has not been so confusing, for the men invariably took considerable exercise on subsequent days or voluntarily curtailed their diet to offset the excess intake. So far as possible,

therefore, we have indicated the probable nitrogen and energy intake of the men in Squad A on the uncontrolled days. Squad B, when on diet, had no uncontrolled meals; hence this problem of uncertainty does not enter into the consideration of their results.

TABLE 34.—*Computed nitrogen and energy in Sunday diets*[1] (*uncontrolled*), *Squad A.*

Subject.	Nitrogen.					Energy (gross).				
	Oct. 28.	Nov.11.	Nov.25.	Dec. 9.	Jan. 13.	Oct. 28.	Nov.11.	Nov.25.	Dec. 9.	Jan. 13.
	gms.	*gms.*	*gms.*	*gms.*	*gms.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Bro....	15.13	14.05	16.13	15.46	20.09	3,758	3,951	3,797	4,152	4,385
Can....	13.45	13.30	13.14	....	17.54	3,088	3,229	3,347	....	3,964
Kon....	12.34	18.36	24.01	....	28.47	2,377	4,569	5,256	....	5,264
Gar....	14.67	23.63	....	24.53	15.34	3,403	4,978	....	4,561	4,521
Gul....	14.01	....	14.05	14.95	28.47	3,671	....	4,830	5,355	5,264
Mon...	12.29	8.77	13.38	12.39	15.80	2,153	3,054	4,660	3,324	3,955
Moy...	17.11	14.34	17.00	18.82	32.70	3,971	3,948	4,763	4,795	6,038
Pea....	23.24	16.15	13.42	21.25	21.20	7,537	4,522	3,310	5,666	5,221
Pec....	18.83	11.69	17.44	20.15	11.30	3,016	2,650	3,541	4,414	2,900
Spe....	14.73	8.93	12.82	....	....	3,248	3,241	3,369	....	....
Tom...	13.52	15.19	15.64	13.62	16.12	2,525	2,925	3,597	3,347	3,024
Vea....	16.01	15.58	12.38	19.79	11.27	4,057	3,647	3,063	4,586	2,524
Av.[2]....	15.44	14.54	15.40	17.88	19.85	3,567	3,701	3,958	4,467	4,278

[1] The uncontrolled diets of Sunday, October 14, 1917, were not reported.
[2] The average nitrogen intake for these Sundays was 16.62 grams and the average gross energy 3,994 calories.

In the last analysis, however, it should be borne in mind that these men were, in a sense, on controlled diet even during these unrestricted periods, for the actual control was the body-weight. They were thoroughly educated in the belief that an increase in body-weight indicated overeating. Judging from the character of the food in the restricted diet, the men had evidently for the most part a relatively low glycogen storage. We have every reason to believe that many of the increases in weight noted with these men were due to the fact that there was on the free days a liberal storage of glycogen, which carried with it a large amount of water. This addition of water would accentuate the increases in weight, a point which has been thoroughly discussed in the section on body-weight. (See pp. 194 and 224.) On the other hand, the men soon found that by rigid training the weight gain could be rapidly lost and the original desired level speedily obtained.

CALORIC ALLOTMENT.

The caloric allotment with Squad A was determined primarily with a view to lowering the body-weight to approximately 10 per cent below the initial weight and subsequently providing sufficient calories to maintain the body-weight at that level. It was believed that

with a group of 12 men the body-weight, carefully measured over a period of several days, if not weeks, could be taken as an index of caloric requirement for weight maintenance. The total amount of calories required to hold the body-weight at maintenance level would thus be the amount actually required for the daily activity of this group of men. Had there been but one subject, we could have apportioned the total daily calories in one meal or one allotment and allowed the subject to eat as freely as he chose throughout the day, either in three meals or in more, if he wished. With certain members of our squad this plan might have been very successful, for not infrequently the desire to eat away from the table was disquietingly strong. For a group of men, however, this method of procedure would give a less strict control. We therefore considered it best for the men to eat at the table under the supervision of a member of the Laboratory staff.

The caloric allotment was not regular from day to day. One might ask why a definite number of calories was not assigned each day, for theoretically this would have been the proper procedure. Practically the caloric allotment was in large part decided by the character of the food served in the regular mess hall by the chef on that particular day. If the food was especially fat-rich, the energy was liable to be large; if it was fat-poor, the energy was low, for we usually attempted to serve small portions, irrespective of the character of the food itself. Consequently, an examination of the tables giving the daily intakes of nitrogen and energy shows relatively large fluctuations from day to day. On the other hand uniform average levels for the intake of energy may be found with practically all the subjects for periods of weeks, as shown in nearly all the tables. These average levels have been blocked in on the body-weight curves (see figs. 57 to 68), the energy intake being in this case the net calories—that is, the caloric intake less the calories of urine and feces.

An inspection of these curves shows that the net calories during comparable periods of time remained fairly uniform from individual to individual. Obviously the large men as well as the more active men required more calories. While there were wide fluctuations from day to day, the averages for a week or ten days are alone to be considered. This method of allowing a reasonably free food intake, without stipulation as to the exact number of calories or grams of nitrogen for each day, made it much easier to use the food ordinarily served in the dining room and thus provide the necessary variety. We still see no reason for altering this procedure.

In summation, therefore, we should state that the diets given to these subjects were, so far as character is concerned, those ordinarily employed in the dining-room. A great variety of foods was supplied. No special dietetic control, such as special amounts of pro-

tein, fats, or carbohydrates, was insisted upon. The sole aim was to alter the energy sufficiently to produce loss in body-weight to a definite point and thereafter to increase the energy only when needed to hold the body at that weight-level.

INTROSPECTION REGARDING DIET.

The data regarding the diets recorded in the previous portion of this chapter are based upon the quantitative measurements. It seems important also to record such of the introspection as is relevant to the character, amounts, palatability, etc., of the diet. As records of the state of mind of these men at the different stages in the experiment, these introspections form a real contribution to the study. The phraseology used by the men is given in most instances, and frequently these statements are given *verbatim*.

SQUAD A.

On the evening of November 10, while at the Nutrition Laboratory, the men were questioned individually along certain lines on the ground that by this time they were accustomed to the experiment and the element of suggestion would play a very small rôle. The questions pertaining to food, together with the answers given by the several subjects, are reported herewith. Records were likewise kept concerning the introspection previous to November 10, which was doubtless colored by the novelty of the situation. In addition, we have the introspections recorded on the various trips to Boston, chiefly in connection with the psychological tests, the chance remarks regarding the diet made at Springfield and noted by the experimenters throughout the entire test, and the introspections (retrospect) obtained by one of us after the close of the experiment on special trips to Springfield.

To avoid repetition we give herewith the substance of the three questions asked of each member of Squad A on November 10; the answers thereto will be found under this date for each subject. (1) What part of the whole experiment thus far has caused you personally the most discomfort or pain, if any? Have hunger pains been experienced, and if so, when? (2) What part of the present diet seems a necessity to you; that is, what tastes best to you or what do you relish most? (3) If allowed to order a meal without restriction, what would you ask for, *i. e.*, what foods have you missed most thus far in the experiment?

Greyson C. Gardner (Gar).

November 10, 1917.—Hungry for 20 minutes or half hour immediately after meals and again about an hour before meals. Likes dessert better than anything else; craves pie and cake especially, also pudding.

November 24, 1917.—No trouble with the diet.

February 2, 1918.—Was hungry all the time before Christmas. The chief difficulty thus far has been his inability to eat in company with people who were having a social time eating together. Has not noticed being hungry

since Christmas so much as before. During last 5 days has not been particularly hungry. Has been underweight most of time. During last 6 or 8 days has been getting double portions; seems to be fairly comfortable on this diet.

February 6, 1918.—Only member of squad at breakfast this morning, following the banquet at home of *Pec* last night.

WESLEY G. SPENCER (SPE).

November 10, 1917.—Hunger has not troubled him very much until this last week; especially hungry an hour or two before dinner and supper. Can not say what tastes best to him, unless possibly ice cream for dessert. Craves nothing specially; when passing fruit stands wishes he could have some fruit, but it does not trouble him; not unusually fond of fruit. Would order, if unrestricted, thin soup, vegetable or fruit salad with plenty of mayonnaise, beefsteak, baked potato, vegetables, and jelly with cream.

November 19, 1917.—"Had a dandy breakfast this morning."

May 22, 1918.—Thinks that at present he is eating a little more than his previous normal diet. Immediately after illness had a tremendous appetite and ate a good deal more, and thinks he is still eating somewhat more than normal diet.

RONALD T. VEAL (VEA).

November 4, 1917.—Refused to take communion at church yesterday, as he did not wish to break training.

November 10, 1917.—Has not felt especially hungry at any time, that is, not enough to be painful; no hunger pains. Relishes meat and potato most; craves nothing special. If allowed to order whatever he wished, would probably get soup and some fish. "If I could just eat food that would go to my legs I would feel perfectly all right."

November 18, 1917.—Would prefer after to-day to leave out of diet all or part of meat.

January 12, 1918.—"I had anything I wanted to eat the first week in Christmas vacation; like particularly bran muffins and apple butter."

February 2, 1918.—Diet given him this week has satisfied hunger. Has not been as hungry as previously.

February 6, 1918.—Had an extra large serving of food at dinner. Ate lightly at night.

February 8, 1918.—"I am not so well now as when on the experiment. I have had diarrhea most of the week when eating uncontrolled. Eating light; only gained about 1 kilogram. I am feeling better to-day, but felt rather weak on previous days, which I thought due to diarrhea, so not so well as when on the diet. I am now trying to go back to more nearly the same amount of food used when on the experiment. I think that I shall feel better."

May 21, 1918.—After diet period is sure he ate more than previous to experiment, to satisfy desire to eat and craving of appetite. During diet period accumulated considerable candy. After experiment ate some of this, but was surprised to find that it did not appeal to him as much as he had expected and he gave most of it away. Used to eat a good deal of candy between meals, but does not now. At present thinks he is eating somewhat less than normally, and does not desire to eat between meals, as he used to do. Thinks his appetite more easily satisfied. This not due to warm weather, but has been observed for several weeks.

LESLIE J. TOMPKINS (TOM).

November 10, 1917.—Regular routine of experiment does not trouble him at all. Does not have material discomfort from absence of food, but ready for

meal whenever it comes. Likes bulky things, as rye bread and carrots. Has no craving for anything special, except for a good meal.

November 16, 1917.—Expresses more or less dislike to having his food reduced.

November 18, 1917.—Remarked yesterday that he preferred to omit from diet all or part of meat and get more bulk.

December 12, 1917.—Has had no bowel movement since first part of week (two or three days). Never calls for bran, but did so to-day.

January 12, 1918.—Spent Christmas vacation in hospital; operation for hemorrhoids. "I refused meat in the hospital."

February 2, 1918.—Says chief inconvenience of experiment has been in having to save urine and feces, but hunger has not troubled him so much. Manages a store and is busy every minute of day and no time to think about being hungry; believes it is because of continuous occupation that he has not noticed hunger so much as some of subjects.

February 6, 1918.—Sick; thinks it due to beans eaten at Laboratory. Has been sick all the week with his stomach. Went to *Pec's* last night and ate more than *Vea.* Went home sick to-day.

February 8, 1918.—*Bro* reports: "I think Mr. Tompkins has returned to his previous condition of piles; that he ate so much following the experiment that he was put out of condition."

February 28, 1918.—"Immediately after the experiment I could not seem to eat enough, which caused considerable discomfort, but that has now disappeared and I am eating normally again."

KIRK G. MONTAGUE (MON).

October 27, 1917.—"I am hungry and sleepy; otherwise all right."

November 10, 1917.—"I know that normally I had been eating too much and I can not help but notice the big change." Has felt no pain at any time; feels weak naturally, because hungry; has not felt hungry until this last reduction in diet; hunger comes on before and after supper. Hard to say what article of diet he enjoys most, because he always enjoys eating everything. Misses ice cream more than anything else. Is hungry all the time or else it is imagination.

November 12, 1917.—Has gas in stomach (after free Sunday).

November 24, 1917.—"I feel better since they have been giving us some bran."

December 8, 1917.—"Yesterday and to-day I have felt better since I have been given more food, as I was 2 full kilograms underweight."

December 19, 1917.—"Not so hungry as I was. More to eat now." (Records show he was getting 2,672 net calories in the latter part of December as compared with 1,935 calories in the early part.)

January 7, 1918.—Abstained from food completely for two days (Saturday and Sunday, January 5 and 6, 1918) to reduce weight.

February 2, 1918.—Says decidedly that present diet is not sufficient to satisfy hunger. Found a great deal of comfort in chewing gum, as several of the subjects have.

February 6, 1918.—Extra large serving of food at dinner. Ate lightly at night. "Professor Burr conducts very interesting classes, but even he notices that we go to sleep in class now. We fall asleep from eating too much."

February 8, 1918.—"There is no weakness or hunger now. Food is not repulsive, and has not been at any time since uncontrolled eating began, nor have I been nauseated. I can study better and I can do my physical work better. On Monday, Tuesday, and Wednesday I had diarrhea; no pain

particularly, but whatever I ate would not remain with me. I have not eaten so much as before the experiment, but it has been a satisfaction to eat what I wanted."

KENNETH B. CANFIELD (CAN).

November 4, 1917.—Took communion at church yesterday.

November 10, 1917.—Has not felt unduly hungry, but "pretty" hungry, usually just before meals. Gluten bread, cake, and occasionally potatoes taste good to him. Relishes particularly steak or chop, French fried potatoes, and hot biscuit. Misses bread, vegetables in large quantity, and ice cream. Is a great bread-eater and likes potatoes, but is not a very great meat-eater. Meat served him at noon would have sufficed for a whole day under ordinary conditions.

December 3, 1917.—Did not eat breakfast. Headache later, probably because of no breakfast.

December 6, 1917.—After good "feed" of day before (1,936 net calories) feels altogether different, more active, finds it easier to study, etc.

December 10, 1917.—Hungry.

February 2, 1918.—Some hunger pains occasionally.

February 5, 1918.—Squad A went to *Pec's* to turkey dinner and all "stuffed to the limit." *Can* had second helping of ice cream.

February 6, 1918.—Bran on dinner table. *Can* took 2 spoonfuls. Ate extra large portion of food for dinner.

February 8, 1918.—"Lately I have eaten in abundance. After getting settled will not eat so much. I regard this period now as a sort of spree."

May 22, 1918.—Feels he has been taking a little too much food and is trying to cut down. This is his aim and his attitude. Says he is not always successful. Is trying to adopt the plan of taking one helping of food at table. Thinks perhaps if the word "normal" is used to mean the diet at the beginning of the experiment, the present diet would be about the same as that. Does not aim to cut down very much, but expects to cut down a little below the previous normal. Thinks in anticipation of hard work will eat a little more.

HENRY A. MOYER (MOY).

November 10, 1917.—No complaints regarding diet. Notices hunger at 8 or 9 o'clock at night and 11 or 12 o'clock in morning; otherwise not particularly hungry. Has had hunger pains a few times, more at beginning, and had to go to bed; has not noticed it much this last week. Thinks it more psychological than physiological. Difficult to say what article of diet he likes best; likes everything. If allowed to order without restrictions would order soup, fish, some sort of vegetable, and probably pie for dessert.

November 12, 1917.—Feels poorly in stomach (after free Sunday).

February 2, 1918.—Only time during week noticed hunger very much was after day in which he received double portions and gained in weight; the next day his food allowance was "cut in halves" to reduce his weight. Inconvenienced by extreme desire for food just before midday meal and supper. Speaks of great difference between periods when weight was actually being reduced by low rations and when diet was sufficient to hold the weight or to allow slight gain in weight; the latter period caused almost no difficulty. Has been in habit of eating between meals a good deal and noticed difference in having to give this up.

February 6, 1918.—Ate extra large helping of food at dinner. Ate lightly at night.

February 8, 1918.—States that Monday and Tuesday he felt "logy" and sleepy, probably from overeating. "Sunday had an ordinary dinner; I tried

not to overeat. Tuesday evening I had a 'big feed' at Mr. Peckham's and after it I felt very uncomfortable, but I had no stomach-ache or indigestion." States that during the diet period when he was hungry he found it most satisfactory to run the typewriter or do some such work rather than try to study; could do as much on Sunday after his full dinner as during the rest of the week, or at least this was his impression.

May 21, 1918.—Is at present eating only two meals a day—breakfast and dinner; did this particularly when writing his thesis, in order to save time and also some money, and because he was convinced he did not need supper. Probably has been eating a little heavier dinner, but not any heavier breakfast. For breakfast has two glasses whole milk, two shredded-wheat biscuits, two slices of bread with butter, and fruit, if there is any. Is sure he is eating very much less food than he did just after the close of the experiment, and thinks he is eating somewhat less than he did normally before the experiment. Between meals during the day sometimes eats three or four chocolates, sometimes not any. Is rather surprised that, since leaving off supper, he does not seem to have a particularly keen appetite for breakfast or dinner.

R. Wallace Peckham (Pec).

October 27, 1917.—"I am very happy to be on the diet squad."

November 10, 1917.—"The amount of food seems mighty small." Has a gnawing pain of hunger about 3 hours before eating; noticeable first 10 days and increased in severity last 2 days, due to fact he had been trying to lose weight by increased physical exercise. Everything tastes good to him, shredded wheat more than anything else. Craves salad, pie, doughnuts, and Rhode Island johnnycakes, probably explained in part by the fact that his family has them at home on the table and he sees them.

November 18, 1917.—Prefers after to-day to leave out of the diet all or part of meat and get more bulky food instead.

November 26, 1917.—"Had a pretty good feed Sunday. Look at my face! See, all the wrinkles are gone!"

December 6, 1917.—Reported as having made the following remark two days before: "We fellows must have reached a pretty bad place when we are ready to cry from hunger."

December 19, 1917.—"I feel fine as silk. Nothing difficult for me now and with this food I have more life and snap."

January 7, 1918.—Reports he has abstained from food completely for two days (Saturday and Sunday, January 5 and 6) to reduce weight.

January 12, 1918.—"No hunger pains now."

January 26, 1918.—"I have dreams at night about food."

February 2, 1918.—With present diet feels no keen sense of hunger. Dreams of food, but thinks it due to approaching end of experiment and that then he will live at home again; is naturally looking forward to it.

February 5, 1918.—Squad A went to *Pec's* to a turkey dinner and everyone "stuffed to the limit." *Pec* had second helping of ice cream.

February 8, 1918.—"I think the men should have been brought back to normal and not allowed to come end over end. Nearly everyone has had difficulty such as diarrhea. In my case it has been very extreme. I ate toast and tea and bran bread, but it continued from Monday evening, February 4, until to-day, February 8. Monday forenoon I was down town. During the period of the experiment I have often noticed in the windows exhibits of food for sale. It always looked most attractive. I went into a shop and bought two doughnuts with apple jelly inside and ate them. It was indiscreet to eat them, but otherwise I was very careful and did not overeat. At noon I had

some steak and johnnycake. In the evening some more johnnycake, and that evening suffered intensely with much gas. Tuesday I ate nothing, but in the evening when we had the banquet I took a small meal. It was a turkey dinner with all the fixings. I had to pay the penalty, and think it was because of the doughnuts, which were eaten first. All the members of the squad took their pulse at the banquet; the rate ranged from 72 to 104." On many evenings during the diet experiment it was necessary for the subject to go to bed immediately after supper, because he was so hungry he could not study satisfactorily.

EVERETT R. KONTNER (KON).

November 10, 1917.—Feels hungry at times, especially just before noon. Misses bread most; likes milk best in present diet list; craves candy.

November 16, 1917.—Does not like food reduction; thinks if food is reduced more he will not be able to study. Was shown his percentage loss in body-weight. Complains of being reduced too rapidly. Asked whether he did not understand that when he was selected to join the squad it was with the understanding that he would have to lose weight rapidly, and replied: "Yes; but I did not understand that I would have to reduce so rapidly that it would interfere with my regular work and put me in a position to be unable to do my work." Asked for double portion of spinach at noon, which he would have received, but there was none left. Was promised all the spinach he wanted. Several members of squad think that *Kon* will be all right later, and endeavor to cheer him up.

January 26, 1918.—Hungry, but not more than usual.

February 2, 1918.—Last three days has not had hunger pains of any consequence. Chief inconvenience has been from weakness and hunger.

February 6, 1918.—Ate considerable at night.

February 8, 1918.—"I did overeat Monday evening. I was not ill, but had a very great feeling of fullness and produced vomiting artificially. The next morning I was all right."

OTTO A. GULLICKSON (GUL).

November 10, 1917.—Tired from overwork rather than from undereating. No complaints; has felt hungry evenings about 11 o'clock after his work at the Boys' Club. "Feel fine; never felt better in my life. Only disagreeable feelings are occasional hunger pains. Otherwise physical condition better than ever before."

November 12, 1917.—Has disorder of bowels (after free Sunday).

December 7, 1917.—Has increased weight $1\frac{1}{4}$ kg. Is dissatisfied because he thinks he should not have been fed so well and "now I have to starve myself again to get my weight down."

December 8, 1917.—"Feel fine and dandy. Better than last week. Have recently increased about 1 kg. and think this is reason why I feel better."

January 7, 1918.—Has abstained from food completely for two days (Saturday and Sunday, January 5 and 6) to reduce weight.

January 12, 1918.—"I am not so effective as I should be, because of not enough to eat, I think."

January 17, 1918.—Said he would eat nothing for two to three days until he had lost his 10 per cent. Had no supper the day before. Took three sticks of gum on January 17 and 18 but nothing else.

February 2, 1918.—"The diet which I have been getting during the last week has been very comfortable. I could go on this diet for the rest of my natural life." "That is, you mean continually?" "Yes, judging by the way I have felt the last three or four days, I believe I could. The hunger pangs

have absolutely disappeared, and those were the disagreeable part of the experiment." There have been times when he has felt severely hungry and at such times he has tended to look on the dark side of the whole situation and feel that he was more deficient in his work than really was the case.

February 5, 1918.—Goes around with vest unbuttoned to relieve strain on stomach. Squad A went to *Pec's* to a turkey dinner and everyone "stuffed to the limit." *Gul* could not eat cake.

February 6, 1918.—Ate an extra large serving of food at dinner. Vomited up his dinner last night. *Vea* remarks: "I don't see how *Gul* eats so much."

February 8, 1918.—"I have had more 'pep' but have been eating so much that any advantage of more food has been offset by the extremely large quantity. My physical work is below par because I am eating so much. Food is repulsive after meals. Yet I do not think that I eat to the limit. I am chewing something all the time, however. This week is a spree; then I will work back to a lower diet of about two meals per day. This has been my usual custom, and I think it is one reason why it was hard for me to cut down."

ALLEN S. PEABODY (PEA).

October 27, 1917.—"Yesterday noon following the race I felt real hungry."

November 10, 1917.—"For the past few days I have taken bran at the table and it has physicked me." Can think of nothing in experiment which has caused him discomfort, except that immediately after meals for about an hour and a half he feels very hungry; has noticed this more on days when the dinner or supper has been rather light; on days when bulky food was served has not noticed it so much. Never feels hungry before or after breakfast. Likes everything.

November 12, 1917.—Does not feel right in stomach (after free Sunday).

December 13, 1917.—With present diet thinks he could continue indefinitely.

January 12, 1918.—"I do not feel nearly so good as when I was eating during vacation. I was working hard and eating then. I gained 22 pounds during vacation. This morning I am down 14 pounds."

February 2, 1918.—In November, when the greatest reduction in diet occurred, felt hungry all the time. With the diet received 10 days before Christmas and again during last 5 days, he could continue indefinitely without discomfort; weight loss now 11.5 per cent. Suffered most discomfort during period of losing weight. When enough food was given to maintain weight, experienced very little discomfort; thinks with diet slightly above present could subsist indefinitely without suffering.

February 6, 1918.—Ate lightly to-night.

February 8, 1918.—"I have an insatiable appetite. I eat all I can hold and then want more. I eat until there is great fullness in the stomach and it hurts me and still I want more. Wednesday morning I went to sleep in class after the Tuesday evening banquet at Peckham's. I believe I am eating too much, of course, and I have little inclination to move, but after I get started I have lots more 'pep' than I used to have during the experiment. Now I have to rise to urinate between 3 and 6 a. m., and I did not have to do it when on the diet."

May 22, 1918.—Thinks he is eating about normally, considering as "normal" his diet before experiment. As he manages the dining hall, he sometimes does not eat much breakfast, but has a little tendency to eat between meals. Thinks the amount no more than normal; not nearly so much as he ate just after experiment was over. He ate no pastries and cakes for a period of four or five weeks when in training. In ten days before Christmas and during last week in January when holding weight level and not reducing, thought

he was getting considerable food. Thinks he could have stayed on that diet indefinitely; was getting practically enough to satisfy him. During actual period of reduction in attempt to lose 10 per cent (15 pounds or so) was uncomfortable and hungry all the time. Frequently, at night, would go to bed because of hunger, and realized he would sleep and in the morning would wake up and go through respiration experiment; then would get something to eat. "When you are getting a very small diet, for the hour and a half after the meal you notice being hungry more than before the meal; you feel almost starved, and crave any food you see; after that this condition seems to pass away. It was a hard matter to have the men at the other tables in the dining-hall eating so much and getting such large helpings and yourself be cut down so low."

GEORGE A. BROWN (BRO).

November 10, 1917.—1,402 net calories on this date. "At times I feel a little weak, but as compared with last year, when eating all I wanted, I now feel much better and have 'pep' left after the day is over." One of the greatest deprivations has been the fact he could not eat candy, etc., between meals; had been in the habit of getting candy and peanuts between meals when going downtown and passing a drugstore; has not felt painfully hungry at any time, but sometimes hungry just before supper. In general potatoes and milk taste best to him. Craves nothing except candy; would order a large steak with plenty of gravy.

December 6, 1917.—Was "terribly" hungry the other day; could not study.

December 8, 1917.—"I feel all right. It is too near meal-time to feel otherwise. I am occasionally hungry."

December 12, 1917.—In evening stomach feels rumbling and queer.

December 19, 1917.—"Not so hungry."

January 12, 1918.—Net calorie intake, 1,536 calories; previous two days, 699 and 883 calories. "I do not have enough to eat. I feel better now than right after supper. I seem to notice the reduction in food more this time than I did the first time. Perhaps the cut is a greater one."

January 14, 1918.—Hungry.

January 15, 1918.—Hungry.

January 16, 1918.—Weak but better (double portion of food).

January 17, 1918.—Feel good but lack "pep," *i. e.*, life and snap (double portion of food).

January 26, 1918.—Net calorie intake, 1,927; averaged about 1,500 calories for the previous 6 days. "The past few days I have been rather weak and hungry at times."

January 29, 1918.—Feel good (double portion of food).

February 2, 1918.—"Is the food you are now getting sufficient to satisfy hunger?" "Yes." "Any hunger pains?" "Not in the last two days." "What has been the chief disagreeable feature of the whole experiment to you?" "Feeling hungry and thinking of all the good things I might have to eat, but particularly hated to go without candy and sweet things of that nature."

February 8, 1918.—"Following the experiment I found that I had lots of gas and a sour stomach, no indigestion or diarrhea, or special pains. Concerning the experiment in general I think several of the men tried to arrange their work to accommodate themselves to the hunger. In my own case I could study pretty well following meals, but an hour or an hour and a half before meals I found it much better to occupy myself in arranging the books on the shelves in the library. I thought of the food so much and it had to be so scientific. If I only could have had a little candy I would have given

up all the bread in a meal for it. If I could have had the food and eaten it when and how I pleased, just the same amount, it would have seemed much better to me. That is, I wanted some freedom in reference to it. Think the matter of intense occupation a big factor in making one able to accommodate himself to a reduced diet and the presence of hunger. I would be willing to stake all on the absolute reliability of the men under the honor system. I would not have gone into the experiment if watched all the time, as then there would have been the attitude of trying to 'put something over'. Dr. Carpenter was at the Laboratory on the evening before the experiment ended when I had some candy or food and told me to be careful or the temptation might be too strong to take some. I laughed and stated that I had two dozen almond bars, several glasses of jelly, and other food in my room all the time, which had been sent me from home by my people or given by local friends. There was absolutely no temptation to take it under the circumstances, but had the people watched us and checked us, I do not know how it would have been then."

"You will have to hand it to Mr. Fox for being able to get on with the 12 men of our squad, who were so crabbed and complaining most of the time. When we found that the food was cut down, for example, the men complained in an almost rude fashion. Some fellow would say, 'Here, what does this mean; don't I get some of this to-day, or some of that other to-day?' Mr. Fox would just calmly reply: 'I did not plan on that.'"

May 21, 1918.—Is now going without midday meals; eats breakfast and supper and thinks that these are not heavier meals than he ate on the three-meal basis, and therefore that he is taking less food than he used to take normally. The experiment ended February 3. Up to the spring vacation, April 3, he ate three meals a day and the amounts eaten were considerably more between February 3 and April 3 than since that time. With regard to a statement sent to Professors Chittenden and Lusk that this régime was not recommended for the army or for men performing severe muscular labor, *Bro* said: "I should say not. I have myself at other times said, 'I should hate to see our soldiers put on that diet'. Under the conditions of an athletic contest two teams may go through substantially the same motions and the same team plays, but one team does it with more snap and gets there quicker; that team is going to win the game. It was just that added snap and punch that the men on the diet lacked and that would be the essential thing that a soldier must have in order to succeed."

In addition to the personal introspections of the men in Squad A regarding the diet, a few statements are given which were recorded by the experimenters during the progress of the experiment.

October 30, 1917.—"It seems as if most of the squad overate on Sunday, October 28; on talking with them they all claim that it knocked them out and they would not fill up again in the same way."

January 21, 1918.—"Complaint of hunger is *comparatively* infrequent."

January 25, 1918.—Written on calendar near table of diet squad: "10 more days, *then we will eat.*" The number of days was changed daily by one of the squad.

January 29, 1918.—"Everything is going on well. The only complaint is generally about being 'hungry'".

January 30, 1918.—"The end of it all is the talk of the town."

January 31, 1918.—"The craving for meat as the particular article of food which would be the most welcomed when the diet was discontinued

after the close of the experiment has never been mentioned, to my knowledge. A good dish of oatmeal with cream, griddle cakes with sirup, ice cream, pies, candy and plenty of it, cake, are the dishes which have generally been mentioned.''

February 5, 1918.—"The diet squad all went to *Pec's* to a turkey dinner and everyone 'stuffed to the limit.' Chef Hall gives our table special dishes of bulky food such as greens and vegetables."

February 6, 1918.—"Bread heavily covered with butter plentifully eaten. Everyone ate to the limit last night.'' "Men ate quite heavily the first part of the week, but are not eating so much now.''

SQUAD B.

The data for the members of Squad B concerning introspection on diet are naturally not so extended as with Squad A. They are accorded here the same treatment as the statements of Squad A. The only note of general interest is the fact that bran was called for by several members of Squad B following the close of the experiment.

EDWARD M. FISHER (FIS).

January 13, 1918.—"I feel empty since being on the diet.''

February 8, 1918.—"I did not overeat after the experiment, although it was a great temptation to keep filling up all the time. During the last seven days I have taken just two meals a day. I found it necessary to cut down. I think I have gained about 3 kg. in weight. I took two doses of salts one week ago to help reduce.''

VICTOR H. HARTSHORN (HAR).

January 13, 1918.—Complains of weariness since going on diet.

January 27, 1918.—"Immediately after meals I am all right.''

February 8, 1918.—"Before I went on the diet experiment I was working at a boarding house and had much meat. A diet somewhat more than I was eating while on the experiment would be fine for me.''

KARL Z. HOWLAND (HOW).

January 13, 1918.—"To-night I feel all right.''

January 19, 1918.—"I feel all right.''

January 27, 1918.—"I feel good to-night. This week all right, only I think of eating so much of the time.''

February 8, 1918.—"Do not feel so well, but my mind is more peaceful, as I can eat whatever I want and when I want it. If during the experiment it had been impossible to get extra food or to get candy I would have been more comfortable. I could have got on better, I believe, if there had been a real need for reducing because of universal scarcity of food.''

ROBERT L. HAMMOND (HAM).

January 9, 1918.—Can not eat fruit or jelly of any kind, as it does not agree with him. Was not obliged to eat it but was not given a substitute.

January 13, 1918.—Feels all right, except for lack of food.

January 19, 1918.—"I feel hungry, but otherwise all right.''

January 27, 1918.—"I feel fine. Could eat, but otherwise all right.''

HAROLD L. KIMBALL (KIM).

January 13, 1918.—"The rheumatism which has troubled me a great deal does not bother me now. It seems to be helped very much by the reduced diet.''

February 8, 1918.—"Since eating uncontrolled my teeth have begun to ache and the old rheumatism is back with a 'bang.' While on diet I could chew without difficulty. I am very much in favor of the diet for my health. After three days of eating the old troubles began to come back. It was not a case of overeating; I was careful, but I wanted meat and ate it."

ROBERT H. LONG (LON).

January 13, 1918.—"I mind the diet; that is, I noticed the lack of food considerably the first two days. Since then I have felt better. To-night I am all right."

January 19, 1918.—"I have not felt very well during the week. I feel fairly good to-night."

January 27, 1918.—"I feel better to-night than on any day this week."

JOHN SCHRACK (SCH).

January 13, 1918.—"I feel quite good, but hungry all the time; always thinking about good things to eat. I eat things now that I did not care for previously and they taste very good, too."

January 19, 1918.—"I feel fine; I have felt pretty good all the week."

January 27, 1918.—"I had gas in the stomach. Not very anxious to go off the diet. I have some things to eat with me, ready for tomorrow, but as hungry as I have been they do not appeal to me greatly."

ALFRED LIVINGSTONE (LIV).

January 13, 1918.—"I am always waiting for meal time to come. Otherwise I never felt better."

January 22, 1918.—"Very hungry."

January 27, 1918.—"Hungry."

CHESTER D. SNELL (SNE).

January 13, 1918.—"Never felt better in my life since I went on the diet."

January 22, 1918.—"Never felt better or more hungry."

January 27, 1918.—"I feel fine to-night. Never felt better in my life. I am even used to being hungry. It doesn't trouble me any more."

GEORGE H. THOMPSON (THO).

January 19, 1918.—"I have been hungry at times."

January 22, 1918.—"Feeling tired and hungry."

January 27, 1918.—"I feel fine. I have been living pretty good. This last week no fault to find with the experiment at all."

FLOYD M. VAN WAGNER (VAN).

January 13, 1918.—"I feel very good since on the diet. No difficulties at all."

January 19, 1918.—"I am well to-night and hungry. This week only the effects of hunger have been felt."

ELTON L. WILLIAMS (WIL).

January 13, 1918.—"The diet gives no discomfort. I have felt some hunger, though."

January 19, 1918.—"I am quite tired to-night. Hard basket-ball yesterday. Went to bed at 12^h30^m a. m.; up at 5 a. m.; was so hungry that I had to get up. I have had some pain in my stomach all the week."

February 8, 1918.—"Difficult to concentrate in study. I could not keep the idea of eating out of my mind. One of the easiest ways to forget eating was to typewrite notes. I missed candy greatly. If I were with people who were all getting low diet and had moderate physical work, as in camp life, it would be much easier."

CALORIC INTAKE NEEDED FOR WEIGHT MAINTENANCE.

One of the fundamentally important features of this research was to find the caloric intake requirement at the lower weight-level, with a view to determining whether, when the body-weight is reduced, the caloric needs are reduced proportionately, or less or more? If the body-weight could be held at the lower level for a considerable period of time, such as several weeks or months, an accurate measurement of the caloric intake would give a true measure of the caloric output or daily need. With practically all of the men in Squad A at certain times during the diet restriction the weight was maintained at a lower level with approximate constancy, but in no instance were these periods of weight maintenance of sufficient length to establish absolutely the true caloric needs. Although we were not able to hold the men at the lower weight-level for a sufficiently long time to determine definitely the caloric needs, further evidence may be obtained from the results of the gaseous metabolism experiments, which will be considered in a succeeding chapter. The period of diet restriction with Squad B was too short to establish a lower weight level for these men.

Reference has already been made, particularly in the discussion of the body-weight charts for Squad A, to the caloric intake at the different periods of the experiment. These caloric intakes have been given in actual figures in the energy tables for the individual subjects. Very considerable variations in the calories for each day were observed, which were due not only to irregularity in the character and amounts of food served from day to day in the dining hall but to the unrestricted days, *i. e.*, the uncontrolled Sundays. These latter were entirely beyond our control, other than as previously outlined at several points in this discussion. In preparing the estimate of the average caloric intake, however, we have invariably included the estimates based upon the reports of the men of the quantities of food eaten on the unrestricted Sundays, as given in table 34. (See p. 270.) It was necessary in our final tables to assume that on the first unrestricted Sunday, October 14, the quantities taken were exactly those on the second unrestricted Sunday, the estimates of which were furnished by the men. No information is at hand in regard to the energy intakes during the Thanksgiving and Christmas recesses. Hence a break must occur in the caloric intake shown on the body-weight charts at these points.

An analysis of the relationship between the caloric intake and the body-weight, and particularly the body-weight at maintenance level, may be made either from the tables showing the balance between the income and outgo, or from the body-weight charts. It is perhaps somewhat more satisfactory to study the subject graphically from the body-weight curves by noting the heights of the various blocks which

correspond to the caloric intake. (See figs. 57 to 68, pp. 210 to 222.) In practically every instance the caloric intake was increased somewhat in the second week in December; in general the height of the block at this time and the height of the block for the last few weeks of the experiment are not far from the same. In other words, we have two periods which represent a fairly close approximation to the caloric intake for weight maintenance, *i. e.*, when the body-weight was either constant or not materially increasing or decreasing. At neither of these times had we the perfect control desired. Nevertheless, these two independent periods, some six weeks apart, give fairly good evidence of the probable maintenance requirement of these men at the lower weight-level.

If we examine the body-weight chart for *Bro*, (fig. 57, p. 210), we find that the initial requirement in the early part of this test on the uncontrolled days was somewhat over 3,000 calories. The calories here, as well as on the other charts, refer only to the net calories, *i. e.*, calories of food less those of feces and urine. On October 4 a diet restriction took place with a fall in energy intake to about 2,200 calories. Further reductions were made but in the early part of December the energy was increased. This increase was determined, not by calculating the number of calories beforehand, but simply by a gradual increase of the diet during this period until the body-weight had become constant. Exactly the same procedure was carried out in the latter part of January, but the assistant in charge of the apportionment at no time determined the exact caloric intake of the food. Thus, both of these levels were adjusted without a previous knowledge of the caloric requirement. This holds true for all of the subjects. On the return of the men to college in January, all of the subjects received a low diet for a short time, to compensate for the increase in body-weight during their absence. With *Bro* we find that the average of the period of maintenance diet in December and January is not far from 2,000 calories. Reference to the individual balance-tables (tables 46 to 58) confirms this. To make the details still clearer, an abstract is given in table 35 of the principal data in the several balance-tables, grouped with regard to the several periods of diet ingestion. Reference to the actual energy available to the body with *Bro* during the period from December 3 to 20 shows that he had 2,091 calories, and from January 16 to February 3, 1,931 calories, making an average for the two periods of 2,011 calories per day. Hence, we may argue that *Bro* at the lower weight-level required 2,000 net calories.

The body-weight chart of *Can* (see fig. 58, p. 212) likewise shows that during December there was an approximate period of maintenance and another similar period in January. From table 35 and from the height of the two energy blocks on *Can's* chart which, as stated before,

Table 35.—*Nitrogen in food, energy available to body, and nitrogen excreted in urine during periods with the different diet levels, Squad A.*[1]

[Averages per day.]

Subject and dates.	Nitrogen in— Food.	Nitrogen in— Urine.	Energy available to body.
Bro.	*gms.*	*gms.*	*cals.*
Normal diet:			
Oct. 1–4, 1917	15.03	11.84	3,049
Reduced diet:			
Oct. 4–15, 1917	11.67	11.12	2,189
Oct. 15–30, 1917	10.86	10.40	1,877
Oct. 30–Nov. 12, 1917	9.03	10.80	1,524
Nov. 12–29, 1917	9.29	9.60	1,582
Dec. 3–20, 1917	10.81	10.59	2,091
Jan. 8–16, 1918	8.05	8.96	1,344
Jan. 16–Feb. 3, 1918	11.49	11.01	1,931
Can.			
Normal diet:			
Oct. 1–4, 1917	15.35	13.76	3,123
Reduced diet:			
Oct. 4–15, 1917	11.55	13.39	2,155
Oct. 15–29, 1917	10.62	11.20	1,833
Oct. 29–Nov. 5, 1917	9.67	10.95	1,516
Nov. 5–16, 1917	10.03	10.97	1,664
Nov. 16–29, 1917	11.61	11.38	2,178
Dec. 3–20, 1917	12.65	11.41	2,479
Jan. 7– 9, 1918	8.56	11.71	1,128
Jan. 9–Feb. 3, 1918	14.15	12.87	2,386
Fre.			
Normal diet:			
Oct. 1–4, 1917	15.33	12.90	3,089
Reduced diet:			
Oct. 4–15, 1917	11.01	11.45	2,179
Oct. 15–25, 1917	10.53	10.80	1,828
Kon.			
Reduced diet:			
Oct. 30–Nov. 29, 1917	9.46	11.70	1,569
Dec. 3–20, 1917	10.08	13.10	1,869
Jan. 12–Feb. 3, 1918	9.26	10.05	1,581
Gar.			
Normal diet:			
Oct. 1–4, 1917	15.88	14.03	3,142
Reduced diet:			
Oct. 4–15, 1917	11.47	11.81	2,167
Oct. 15–29, 1917	10.30	10.78	1,791
Oct. 29–Nov. 12, 1917	10.36	10.10	1,781
Nov. 12–29, 1917	9.57	9.98	1,712
Dec. 3–20, 1917	12.79	10.33	2,400
Jan. 7–18, 1918	7.39	10.42	1,276
Jan. 18–Feb. 3, 1918	10.49	9.90	1,847
Gul.			
Normal diet:			
Oct. 1–4, 1917	15.57	12.60	3,177
Reduced diet:			
Oct. 4–15, 1917	11.65	11.58	2,229
Gul—continued.	*gms.*	*gms.*	*cals.*
Reduced diet:			
Oct. 15–29, 1917	11.21	11.10	1,951
Oct. 29–Nov. 12, 1917	9.16	10.06	1,554
Nov. 12–29, 1917	9.41	9.47	1,711
Dec. 3–20, 1917	10.39	10.24	2,005
Jan. 5–13, 1918	6.65	9.07	1,083
Jan. 13–Feb. 3, 1918	9.11	8.29	1,607
Mon.			
Normal diet:			
Oct. 1–4, 1917	15.67	12.84	3,155
Reduced diet:			
Oct. 4–15, 1917	11.57	11.91	2,087
Oct. 15–Nov. 1, 1917	11.06	10.88	1,792
Nov. 1–19, 1917	9.45	10.93	1,594
Nov. 19–29, 1917	11.10	10.94	2,153
Dec. 3–10, 1917	10.75	12.88	1,935
Dec. 10–20, 1917	13.98	11.35	2,672
Jan. 7–15, 1918	11.00	10.54	1,895
Jan. 15–Feb. 3, 1918	12.80	11.29	2,126
Moy.			
Normal diet:			
Oct. 1–4, 1917	15.15	12.32	3,074
Reduced diet:			
Oct. 4–15, 1917	11.56	11.02	2,164
Oct. 15–29, 1917	11.06	11.70	1,908
Oct. 29–Nov. 12, 1917	9.48	11.31	1,564
Nov. 12–29, 1917	9.43	10.43	1,627
Dec. 3–20, 1917	11.01	10.76	2,095
Jan. 8–13, 1918	7.85	12.62	1,149
Jan. 13–25, 1918	10.81	11.24	1,723
Jan. 25–Feb. 3, 1918	11.27	10.91	1,958
Pea.			
Normal diet:			
Oct. 1–4, 1917	15.47	13.31	3,127
Reduced diet:			
Oct. 4–15, 1917	11.89	14.15	2,292
Oct. 15–29, 1917	11.58	13.68	2,160
Oct. 29–Nov. 16, 1917	10.16	12.22	1,736
Nov. 16–29, 1917	11.68	10.32	2,174
Dec. 3–20, 1917	13.22	11.36	2,549
Jan. 7–25, 1918	9.22	10.01	1,508
Jan. 25–Feb. 3, 1918	13.38	12.05	2,318
Pec.			
Normal diet:			
Oct. 1–4, 1917	15.66	13.02	3,117
Reduced diet:			
Oct. 4–15, 1917	12.13	12.89	2,124
Oct. 15–29, 1917	11.57	12.15	1,862
Oct. 29–Nov. 29, 1917	9.43	11.68	1,507
Dec. 3–9, 1917	9.79	10.95	1,617

[1] See detailed results in tables 46 to 58.

TABLE 35.—*Nitrogen in food, energy available to body, and nitrogen excreted in urine during periods with the different diet levels, Squad A.*[1]—continued.

[Averages per day.]

Subject and dates.	Nitrogen in— Food.	Nitrogen in— Urine.	Energy available to body.	Subject and dates.	Nitrogen in— Food.	Nitrogen in— Urine.	Energy available to body.
PEC—continued.	*gms.*	*gms.*	*cals.*	TOM—continued.	*gms.*	*gms.*	*cals.*
Reduced diet:				Reduced diet:			
Dec. 9–20, 1917	11.48	11.23	2,196	Oct. 13–30, 1917	10.67	9.48	1,812
Jan. 5–20, 1918	8.10	11.04	1,326	Oct. 30–Nov. 19, 1917	8.89	9.31	1,400
Jan. 20–Feb. 3, 1918	9.57	9.78	1,619	Nov. 19–28, 1917	9.16	7.32	1,705
				Dec. 3–14, 1917	7.92	7.41	1,506
SPE.				Dec. 14–20, 1917	9.76	8.11	1,953
Normal diet:				Jan. 12–25, 1918	7.60	7.48	1,289
Oct. 1–4, 1917	16.09	14.35	3,208	Jan. 25–Feb. 3, 1918	8.82	7.71	1,662
Reduced diet:							
Oct. 4–15, 1917	11.72	12.25	2,185	VEA.			
Oct. 15–29, 1917	10.89	11.75	1,864	Normal diet:			
Oct. 29–Nov. 12, 1917	9.69	11.78	1,656	Oct. 1–4, 1917	15.57	13.88	2,821
Nov. 12–17, 1917	10.00	11.57	1,524	Reduced diet:			
Nov. 17–29, 1917	11.52	11.00	2,302	Oct. 4–15, 1917	11.61	11.24	2,247
Dec. 3–13, 1917	11.61	11.50	2,173	Oct. 15–30, 1917	10.64	10.81	1,855
				Oct. 30–Nov. 12, 1917	9.05	10.40	1,486
TOM.				Nov. 12–29, 1917	8.58	10.05	1,498
Normal diet:				Dec. 3–20, 1917	9.57	10.22	1,836
Oct. 1–4, 1917	14.91	9.66	3,082	Jan. 7–15, 1918	9.81	9.14	1,609
Reduced diet:				Jan. 15–Feb. 3, 1918	11.36	10.95	1,909
Oct. 4–13, 1917	11.43	9.75	2,081				

[1] See detailed results in tables 46 to 58.

were independently established by simply giving such an amount of food as would hold the weight constant without the pre-determination of the caloric value, we find that during the first maintenance period (December 3 to 20) he required 2,479 calories and during the second period, (January 9 to February 3) the requirement was 2,386 calories. A close examination of the curves, however, shows a slight tendency for the body-weight to fall during these periods and we may state in round numbers that *Can* required 2,500 calories for maintenance at this lower level.

With *Kon* the conditions are somewhat different, inasmuch as he joined Squad A several weeks after the experiment was begun. The reduction in diet was therefore somewhat stringent and no clearly defined period of constancy in body-weight can be noted from the body-weight curve. (See fig. 59, p. 213.) There is, however, a tendency for the body-weight to be maintained at constancy between December 3 and 20, although the last weight shows a decided fall. In January the energy intake was adjusted to a lower level to compensate for the great increase in body-weight during the Christmas recess; during the last 10 days in January the weight remained very constant at this caloric intake. If we are to consider this energy

intake as the probable need at this level, we may say that the body-weight was maintained with approximately 1,600 calories. But the evidence is not so clear as one could wish.

With *Gar* the reduction in body-weight followed the usual course. (See fig. 60, p. 214.) It became necessary in the early part of December to give a larger diet than before, to hold the body-weight at a constant level. Again, in the latter part of January, the food intake was increased after a preliminary reduction to offset the increased body-weight with which he returned to college. The body-weight was thus held approximately constant with a considerably lower energy intake than that in December. Probably an average of the two energy intakes will not be far from the correct value for the actual need, and we can say that 2,000 calories was the caloric requirement of *Gar* at the lower weight-level.

With *Gul* the body-weight was essentially constant in December with practically 2,000 calories, and in the last two weeks in January with 1,600 calories. (See fig. 61, p. 215.) We have reason to believe that this subject, who was unusually active physically, might have altered his activities somewhat between these two periods. An exact measure of this difference is hard to obtain, but it would not be unreasonable to assume that an average of the energy intake for the two periods represents the probable caloric requirement, namely, 1,800 calories.

With *Mon* dietetic readjustments were made somewhat frequently, owing to rather sharp falls in body-weight. (See fig. 62, p. 216.) Perhaps the best level is that indicated in the latter part of January, which shows that the caloric requirement of this man is not far from 2,000 calories.

With *Moy* the body-weight was held constant in December with an energy intake of approximately 2,100 calories, and again in January with the available calories slightly below the December intake. (See fig. 63, p. 217.) An average value of 2,000 calories will probably represent his caloric requirement at the lower weight-level.

One of the most physically active subjects we had was *Pea*. His body-weight was held at a low level over a considerable period of time during December with an intake of approximately 2,500 calories. (See fig. 64, p. 218.) The evidence indicates that during the latter part of January and the first of February 2,300 calories sufficed for this subject. We may therefore assume that 2,400 calories approximates his maintenance requirement.

Pec had great difficulty in reducing to a low weight-level and the dietetic readjustments were necessarily frequent. The body-weight was held approximately constant from January 20 to February 3 at not far from 1,600 calories, which may be taken as his maintenance requirement. (See fig. 65, p. 219.)

The unfortunate illness of *Spe* necessitated the conclusion in December of the observations with him. His chart, however, shows with reasonable clearness that the intake of about 2,200 calories would suffice to hold his body-weight constant. (See fig. 66, p. 220.) Unfortunately, in this instance we have not the usual verifying period during January.

The subject most sedentary in habits, and the one who had the most difficulty in securing a reduction in weight, was *Tom*. Unquestionably, the calories in the diet during the first few days were more than he needed, and the dietetic curtailment prescribed for the rest of the men was not sufficient to reduce his body-weight; the intake was accordingly lowered still further. The blocks in his body-weight curve, (see fig. 67, p. 221), show an approximate constancy at the lower weight level with an intake of not far from 1,600 calories. This subject did not lose as much weight as the others, and his loss of nitrogen was materially less than that of the other men.

One of the most regular body-weight curves in the whole series is that of *Vea*, who lost weight very regularly, established an approximate level with 1,850 calories in December, and again essentially the same level in January with 1,900 calories. (See fig. 68, p. 222.) We may thus take 1,900 calories as his probable maintenance requirement.

We have presented in table 36 the probable caloric requirements of these men for maintenance at the lower weight-levels. These values, given in round numbers, range from a minimum of 1,600 calories with *Kon*, *Tom* and *Pec* to a maximum of 2,500 calories with *Can*. At first sight *Can's* requirement appears inconsistent, for although *Can* was the heaviest man in the group, he was by no means so active athletically as some of the other men. The man who was probably the most active (*Pea*) shows, however, a maintenance requirement of 2,400

TABLE 36.—*Net energy required for weight maintenance at low weight-level—Squad A.*

[Derived from body-weight curves. See figs. 57 to 68.]

Subject.	Calories.	Subject.	Calories.	Subject.	Calories.
Bro.....	2,000	Mon....	2,000	Tom....	1,600
Can.....	2,500	Moy....	2,000	Vea.....	1,900
Kon....	1,600	Pea.....	2,400		
Gar.....	2,000	Pec.....	1,600	Avg...	1,967
Gul.....	1,800	Spe.....	2,200		

calories. To those of us who know the men individually, the most surprising figures in the table are the low values with *Pec* and *Kon*. With *Kon*, it will be remembered, somewhat unsatisfactory figures were obtained, and we are uncertain as to whether the energy intake cited is the actual maintenance level. On the other hand, the

picture for *Pec* is reasonably clear. It is not impossible that the latter's age (44 years) may have had an effect upon the energy requirement, for we know that the older a man is the greater the tendency is towards a lower basal metabolism. Averaging the values for the 12 men, we have an average value of 1,967 net calories for maintenance at the lower weight-level, *i. e.*, in round numbers, 1,950 net calories.

The significance of this low figure is perhaps best emphasized when one refers to the probable caloric requirement for weight maintenance prior to dietetic restriction. For this we have two sources of information: (1) the nitrogen balance (see tables 46 to 58, pp. 312 to 341) and (2)the summary in table 35 of the net caloric intake in the so-called "normal diet" from October 1 to 4; this intake averaged not far from 3,100 calories. If we examine the nitrogen in the food for these days, also given in table 35, it is clear that the amounts of food taken by these men were not the amounts normally taken by them. In the first place, they could not consciously have selected so uniform a nitrogen intake as they actually showed. In the second place, Chef Hall, who was very observant, pointed out to us that the men in Squad A in the normal-diet period of October 1 to 4 showed less appetite for their food than previously. On the first return of the college students in the autumn, they usually eat with great appetite, as the food is new to them and they enjoy it very much. There is then a period, usually of a week or ten days, when there seems to be a distinct slackening in the appetite, this actually having an effect upon the purchase and preparation of food in the kitchen. Subsequently they return to their normal appetite and food intake. It was our misfortune to have selected this period of low appetite in which to study the normal diet of these men. Mr. Hall's observation seems to be fully verified by the results of a study with a control squad on normal diet November 20 to 24, which are given in table 32 (p. 268). On 5 days 12 men showed an average energy intake of 4,104 gross calories per day. Deducting approximately 8 per cent, or 328 calories, for the energy outgo in urine and feces, we have 3,776 calories as the average net calories available for this period.

An inspection of the data for the calories in feces and urine for the first three days of October in the several balance tables (pp. 312 to 341) shows that the estimate of 8 per cent for outgo in urine and feces is not unreasonable. This would imply, therefore, that the normal food requirement of the average undergraduate student in the Springfield Y. M. C. A. College was, during the period of November 20 to 24, when this control squad was studied, nearer 3,800 calories than the 3,100 calories shown for Squad A in table 35. On the assumption that the normal energy requirement is 3,800 calories, the average caloric requirement of 1,950 calories found to hold the body-weight at the lower level was thus a little over one-half of the normal require-

ment; in other words, the caloric requirement had been lowered nearly one-half. Using the level of 3,100 calories actually found with Squad A from October 1 to 4, we see that the dietetic restrictions have lowered the caloric requirement 1,150 calories, or a little more than one-third. Even if we raise slightly the caloric requirement at the lower level of body-weight, we would still have reduced the normal requirement of 3,100 calories not less than one-third. It must again be pointed out, however, that body-weight is a very uncertain criterion of the condition of the body reserves. A period of two weeks is too short to obtain results of definite significance. In this particular case, however, with the majority of our subjects two periods separated by nearly a month or six weeks indicated approximately the same uniformity of weight-level with the same caloric intake; hence, we believe we are more justified in using these short periods of constancy in body-weight as a measure of maintenance than if we had but one period. The general conclusion can be drawn, therefore, that using the constancy in body-weight at the lower level as a criterion, the food requirements are approximately one-third less than they are at the higher level.

DIGESTION EXPERIMENTS.

Normal, healthy man, subsisting upon modern well-prepared and well-cooked food materials, exhibits a uniformity of digestive processes that is, in a sense, rather remarkable. The so-called "digestibility" of our modern food materials can be predicted from standard figures with great accuracy. Hence a digestion experiment as such, particularly when ordinary food materials are used, is hardly justifiable. On the other hand, with a great restriction in diet, the evidence is not sufficiently extensive to show whether or not there would be a disturbance in the digestive processes. One criticism of the classic experiment of Professor Chittenden[1] with soldiers was that the amount of nitrogen excreted in the feces of a group of men, presumably with low diet, varied within very wide limits from that which would be expected, or was regularly found with normal individuals. This suggested the possibility, at least, that a restriction in protein had resulted in an actual disturbance of the digestion processes. It therefore became necessary with our subjects to make periodic, so-called "digestion experiments."

These digestion experiments were made with two purposes in view: (1) to note abnormalities if they existed, and (2) to give positive information as to the amount of unoxidized material leaving the body from the alimentary tract. Theoretically, it would have been best to have had a collection of feces throughout the entire time, but this presented technical difficulties which were so great as to make such

[1] Chittenden, Physiological economy in nutrition, New York, 1907, p. 131.

collection impracticable. We were able, however, to obtain six or seven digestion periods with most of the men in Squad A, these ranging from 3 to 16 days each. The first was October 1 to 4, when the subjects were on normal diet; subsequent periods on reduced diet were from October 8 to 12, October 17 to 21, October 31 to November 4, November 12 to 18, December 10 to 15, and finally, a period of a little over two weeks, January 14 to 30. This schedule was followed by practically all of the subjects except *Pec*, whose habits of defecation were so abnormal as to make it impossible for him to carry out this program satisfactorily. With Squad B one digestion experiment was made, January 15 to 23, when the men were on a reduced diet.

The common interpretation of digestion experiments is based upon a fundamentally erroneous conception that the feces represent primarily undigested food. The presence of visible portions of undigested material in feces naturally leads to this belief, but chemical and microscopic analysis shows this is far from the case, and that the feces consist in large part of bacteria, intestinal débris, and residues of digestive juices. Consequently it is clearly erroneous to determine the digestibility of any given nutrient by the comparison, for example, of the amount of protein in the food and the amount of protein in feces. In our experiments no attempt was made to determine the so-called bacterial nitrogen or the so-called metabolic nitrogen; but since our work was primarily a matter of relative comparisons, we have adhered to the archaic form and present our data for these digestion experiments in terms of the utilization of nitrogen and the availability of energy in food for digestion periods. The nitrogen in feces is subtracted from the nitrogen in food and the remainder considered as utilized nitrogen, and the percentage of the total ingested is recorded as the percentage of nitrogen utilized. Similar treatment is given the data for energy, except that not only the calories in feces are deducted from the energy in the food, but likewise the calories in the urine. The calories in the urine are computed by multiplying the nitrogen in the urine by the factor 8.0. The total net calories are thus the total calories in food less those in feces and urine. The percentage of the total net calories compared to the total energy in the food ingested is expressed as availability of energy.

It is a matter of considerable regret that experimental evidence on the character of the feces has been for so many years neglected. Even the present available data regarding this are very fragmentary and no rational method for the comparison of food intake with the several ingredients of the feces is as yet universally employed. One frequently sees the statement that feces are formed during fasting. Whatever may be the case with animals, it is certain that during the 31-day fasting experiment at the Nutrition Laboratory with man no evidence was obtained of fasting feces. On the other hand, evidence was ob-

tained to show that fasting does not completely kill the bacterial action, for Professor Kendall[1] found bacteria in the colon. With the confusion existing at the present time, not only as to a classification of the exact facts known, but more especially with regard to the absence of any logical method of procedure, we must for the present adhere simply to the original plan of considering the nitrogen in the feces as being derived from food, and express our results according to the commonly accepted method.

In our digestion experiments we do not consider the digestibility of fat. It should be pointed out here that the common methods for analyzing the feces are wholly unsuited for the proper determination of the digestibility of fats, for the very large proportion of soaps in feces which are insoluble in ether makes a crude ether extract of feces wholly unsuitable for an estimate of the total fat content. In this research we are primarily interested in the question of whether or not there is a profound disturbance in the proportion of nutrients digested, as commonly expressed, when a diet is used which is very low in calories and moderately low in nitrogen.

DIGESTION EXPERIMENTS WITH SQUAD A ON REDUCED DIET.

The results of our observations for Squad A are recorded in table 37 in grams of nitrogen per day in food and feces and in calories of energy per day in food, feces, and urine. The total and percentage of nitrogen utilized, and the total and percentage of energy available are also given. The differences in the utilization of nitrogen between the beginning and end of the experiment are extremely small, rarely amounting to more than 4 per cent. Hence it would be incorrect to state that there was a pronounced relationship between the amount of nitrogen in food and the nitrogen utilized.

Special attention should be called to the fecal nitrogen. While the character of the diet and the necessity for changing individual diets to maintain weight made it impossible to secure uniformity of nitrogen intake in all instances, we find that on October 8 to 12, the nitrogen in the intake was relatively constant for all men, that is, the values were all between 12 and 12.5 grams. The fecal nitrogen per day for these 12 men was as follows: 1.54, 1.35, 1.56, 1.33, 0.96, 1.22, 1.41, 1.22, 1.37, 1.33, 1.21, 1.02 grams, respectively; in other words, there was a maximum variation of 0.60 gram. This means, then, that when the same amount of food and essentially the same combinations of food, with practically the same nitrogen content, passed through 12 digestive tracts, the fecal nitrogen varied only from 0.96 to 1.56 grams. The period of study was, however, only 4 days. Since this particular test was begun on the fifth day of the restriction in diet, it is hardly probable that we can consider it as more than a normal

[1] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 232.

TABLE 37.—*Nitrogen utilized and energy available from food in digestion periods—Squad A.*

Subject.	Date.	Nitrogen per day—		Nitrogen utilized.		Energy per day—			Net energy.	
		(*a*) In food.	(*b*) In feces.	(*c*) Total (*a*-*b*).	(*d*) Per cent $\frac{c \times 100}{a}$	(*e*) In food.	(*f*) In feces.	(*g*) In urine ($N \times 8.0$)	(*h*) Total [$e-(f+g)$]	(*i*) Per cent $\frac{h \times 100}{e}$
Bro....	Normal diet:	*gms.*	*gms.*	*gms.*		*cals.*	*cals.*	*cals.*	*cals.*	
	Oct. 1–4, 1917...	15.03	1.95	13.08	87	3,310	166	95	3,049	92
	Reduced diet:									
	Oct. 8–12, 1917..	12.41	1.54	10.87	88	2,322	171	91	2,060	89
	Oct. 17–21, 1917..	11.09	0.72	10.37	94	1,979	124	90	1,765	89
	Oct.31–Nov.4,1917	8.12	0.73	7.39	91	1,487	105	85	1,297	87
	Nov. 12–18, 1917..	9.58	1.24	8.34	87	1,672	160	81	1,431	86
	Jan. 14–30, 1918..	9.74	1.18	8.56	88	1,831	145	80	1,606	88
Can....	Normal diet:									
	Oct. 1–4, 1917...	15.35	1.36	13.99	91	3,367	134	110	3,123	93
	Reduced diet:									
	Oct. 8–12, 1917..	12.31	1.35	10.96	89	2,320	147	111	2,062	89
	Oct. 17–21, 1917..	10.98	0.86	10.12	92	1,970	113	100	1,757	89
	Oct.31–Nov.4,1917	9.07	1.07	8.00	88	1,724	138	93	1,493	87
	Nov. 12–18, 1917..	10.32	1.24	9.08	88	1,911	168	93	1,650	86
	Dec. 10–15, 1917..	13.59	1.76	11.83	87	2,972	231	88	2,653	89
	Jan. 14–30, 1918..	14.37	1.76	12.61	88	2,734	215	104	2,415	88
Fre.....	Normal diet:									
	Oct. 1–4, 1917...	15.33	1.86	13.47	88	3,346	154	103	3,089	92
	Reduced diet:									
	Oct. 8–12, 1917..	12.10	1.56	10.54	87	2,268	145	89	2,034	90
	Oct. 17–21, 1917..	10.45	0.90	9.55	91	1,886	82	91	1,713	91
Kon....	Reduced diet:									
	Oct.31–Nov.4,1917	9.04	0.87	8.17	90	1,574	125	103	1,346	86
	Nov. 12–18, 1917..	8.65	1.06	7.59	88	1,487	150	95	1,242	84
	Dec. 10–15, 1917..	9.06	1.07	7.99	88	1,952	150	96	1,706	87
	Jan. 15–30, 1918..	7.79	0.88	6.91	89	1,502	129	78	1,295	86
Gar....	Normal diet:									
	Oct. 1–4, 1917...	15.88	1.77	14.11	89	3,399	145	112	3,142	92
	Reduced diet:									
	Oct. 8–12, 1917..	12.05	1.33	10.72	89	2,271	137	98	2,036	90
	Oct. 17–21, 1917..	10.67	1.25	9.42	88	1,917	106	97	1,714	89
	Oct.31–Nov.4,1917	8.93	1.07	7.86	88	1,726	109	85	1,532	89
	Nov. 12–18, 1917..	9.63	0.99	8.64	90	1,821	132	78	1,611	89
	Dec. 10–15, 1917..	13.20	2.35	10.85	82	2,896	275	82	2,539	88
	Jan. 14–30, 1918..	8.67	1.19	7.48	86	1,688	136	76	1,476	87
Gul....	Normal diet:									
	Oct. 1–4, 1917...	15.57	1.13	14.44	93	3,385	107	101	3,177	94
	Reduced diet:									
	Oct. 8–12, 1917..	12.37	0.96	11.41	92	2,331	140	117	2,074	89
	Oct. 17–21, 1917..	11.61	1.01	10.60	91	2,087	149	99	1,839	88
	Oct.31–Nov.4,1917	9.50	0.87	8.63	91	1,780	129	89	1,562	88
	Nov. 12–18, 1917..	9.53	0.91	8.62	91	1,688	127	83	1,478	88
	Dec. 10–15, 1917..	10.44	1.54	8.90	85	2,231	226	83	1,922	86
	Jan. 14–30, 1918..	7.20	1.05	6.15	85	1,472	152	68	1,252	85
Mon...	Normal diet:									
	Oct. 1–4, 1917...	15.67	1.59	14.08	90	3,406	148	103	3,155	93
	Reduced diet:									
	Oct. 8–12, 1917..	12.40	1.22	11.18	90	2,328	135	95	2,098	90
	Oct. 17–21, 1917..	11.38	1.24	10.14	89	2,053	162	92	1,799	88
	Oct. 31–Nov. 4, 1917...........	9.50	0.98	8.52	90	1,772	126	91	1,555	88
	Nov. 12–18, 1917..	9.97	1.33	8.64	87	1,832	170	89	1,573	86
	Dec. 10–15, 1917..	13.92	2.14	11.78	85	3,003	269	85	2,649	88
	Jan. 14–30, 1918..	12.02	1.55	10.47	87	2,246	188	88	1,970	88

TABLE 37.—*Nitrogen utilized and energy available from food in digestion periods—Squad A*—continued.

Subject.	Date.	Nitrogen per day—		Nitrogen utilized.		Energy per day—			Net energy.	
		(a) In food.	(b) In feces.	(c) Total (a–b).	(d) Per cent $\frac{c\times100}{a}$	(e) In food.	(f) In feces.	(g) In urine (N×8.0)	(h) Total [e–(f+g)]	(i) Per cent $\frac{h\times100}{e}$
Moy...	Normal diet:	gms.	gms.	gms.		cals.	cals.	cals.	cals.	
	Oct. 1–4, 1917...	15.15	1.51	13.64	90	3,325	152	99	3,074	92
	Reduced diet:									
	Oct. 8–12, 1917..	12.18	1.41	10.77	88	2,295	161	90	2,044	89
	Oct. 17–21, 1917..	11.27	0.96	10.31	91	2,025	130	90	1,805	89
	Oct. 31–Nov. 4, 1917...........	9.10	1.11	7.99	88	1,649	139	99	1,411	86
	Nov. 12–18, 1917..	9.48	1.44	8.04	85	1,673	175	91	1,407	84
	Dec. 10–15, 1917..	11.17	1.38	9.79	88	2,411	167	83	2,161	90
	Jan. 14–30, 1918..	9.21	1.11	8.10	88	1,721	148	92	1,481	86
Pea.....	Normal diet:									
	Oct. 1–4, 1917...	15.47	1.39	14.08	91	3,364	131	106	3,127	93
	Reduced diet:									
	Oct. 8–12, 1917..	12.22	1.22	11.00	90	2,302	191	119	1,992	87
	Oct. 17–21, 1917..	11.07	0.99	10.08	91	1,993	145	117	1,731	87
	Oct. 31–Nov. 4, 1917...........	9.42	0.81	8.61	91	1,813	135	108	1,570	87
	Nov. 12–18, 1917..	10.45	1.18	9.27	89	1,967	163	92	1,712	87
	Dec. 10–15, 1917..	13.24	1.70	11.54	87	2,871	259	94	2,518	88
	Jan. 14–30, 1918..	9.90	1.24	8.66	87	1,870	172	81	1,617	87
Pec....	Reduced diet:									
	Oct. 8–12, 1917..	12.49	1.37	11.12	89	2,361	191	103	2,067	88
	Oct. 17–21, 1917..	11.79	0.92	10.87	92	2,114	175	105	1,834	87
	Oct. 31–Nov. 29, 1917...........	9.25	0.96	8.29	90	1,734	143	92	1,499	86
	Dec. 10–15, 1917..	10.24	1.08	9.16	90	2,189	179	89	1,921	88
	Jan. 14–30, 1918..	8.61	0.96	7.65	89	1,621	134	78	1,409	87
Spe....	Normal diet:									
	Oct. 1–4, 1917...	16.09	1.52	14.57	91	3,445	122	115	3,208	93
	Reduced diet:									
	Oct. 8–12, 1917..	12.33	1.33	11.00	89	2,324	146	101	2,077	89
	Oct. 17–21, 1917..	11.14	0.84	10.30	92	2,003	112	98	1,793	90
	Oct. 31–Nov. 4, 1917...........	9.50	1.10	8.40	88	1,820	138	95	1,587	87
	Nov. 12–18, 1917..	9.42	1.39	8.03	85	1,938	168	89	1,681	87
Tom...	Normal diet:									
	Oct. 1–4, 1917...	14.91	1.32	13.59	91	3,286	127	77	3,082	94
	Reduced diet:									
	Oct. 8–12, 1917..	12.33	1.21	11.12	90	2,324	151	80	2,093	90
	Oct. 17–21, 1917..	11.01	1.05	9.96	90	1,974	129	84	1,761	89
	Oct. 31–Nov. 4, 1917...........	8.83	0.79	8.04	91	1,604	114	84	1,406	88
	Nov. 12–18, 1917..	8.87	1.04	7.83	88	1,513	133	72	1,308	86
	Dec. 10–15, 1917..	7.34	0.92	6.42	87	1,612	115	65	1,432	89
	Jan. 14–30, 1918..	7.37	0.87	6.50	88	1,439	94	59	1,286	89
Vea....	Normal diet:									
	Oct. 1–4, 1917...	15.57	1.19	14.38	92	3,052	120	111	2,821	92
	Reduced diet:									
	Oct. 8–12, 1917..	12.01	1.02	10.99	92	2,264	124	91	2,049	91
	Oct. 17–21, 1917..	10.84	0.82	10.02	92	1,951	104	95	1,752	90
	Oct. 31–Nov. 4, 1917...........	8.67	1.06	7.61	88	1,577	147	86	1,344	85
	Nov. 12–18, 1917..	9.27	0.78	8.49	92	1,621	113	82	1,426	88
	Dec. 10–15, 1917..	9.40	0.95	8.45	90	2,034	138	83	1,813	89
	Jan. 14–30, 1918..	10.59	1.14	9.45	89	2,008	163	86	1,759	88

digestion experiment, or an experimental verification of the earlier contention that under these conditions the digestibility of nitrogen, to use the older term, is the same with practically all healthy men.

The comparison of the digestibility in the later series after the men had been for some time upon the low diet is somewhat difficult, owing to the decidedly wide variations in the food ingestion. In fact, the nitrogen in food per day varied so widely with the different men after the middle of October that no considerable number of days can be selected to study the uniformity of the relationship between food nitrogen and fecal nitrogen. This will be implied from the percentage values for the utilization of nitrogen. But none of the figures show an abnormal nitrogen utilization. The low values, which fall to 82 and 85 per cent, are comparable with other observations, especially when it is remembered that the amount of animal protein was somewhat decreased in these observations.

The largest excretions of total nitrogen in the feces are those for *Gar* and *Mon* on December 10 to 15. These values correspond to their highest nitrogen intake other than in the first digestion period, that is, 13.20 grams with *Gar*, and 13.92 grams with *Mon*. That the presence of bran in the diet does not affect the nitrogen in feces is strikingly shown by the fact that *Gar* had no bran during the period of December 10 to 15 while *Mon* consumed 168 grams. Thus, one must be somewhat conservative in putting emphasis upon the presence of bran in the diet in considering the utilization of nitrogen. The conclusion can, however, be fairly drawn that the reduction in diet did not materially alter the digestibility of nitrogen.

The lowest utilization of nitrogen occurred with 7 of the 12 men in the digestion experiment of December 10 to 15, but an examination of the intake of nitrogen shows that this usually represented a period of high rather than low nitrogen intake, so that the low utilization of nitrogen is not coincidental with low nitrogen in the intake, as perhaps might be expected. In 5 cases, *Vea*, October 31 to November 4, *Spe*, November 12 to 18, *Tom*, December 10 to 15, *Gul* and *Pec*, January 14 to 30, we find the lowest utilization of nitrogen coincidental with the lowest nitrogen in food.

The available energy was, in all instances, highest during the first digestion period, that is, when the men were on normal diet. During the first digestion period the available energy averaged for the squad measurably above 92 per cent. Thereafter there was a distinct tendency for it to fall, values as low as 85 or 86 per cent being occasionally found. The absolute minimum was 84 with *Moy* and *Kon* on November 12 to 18. Seven of the men show the lowest available energy in the experiment of November 12 to 18. With all of the men the tendency is for the lowest available energy to occur with the minimum calories in the diet, this being in rather striking contrast to the evidence for the utilization of nitrogen.

The indigestible bran in the diet unquestionably raised perceptibly the true undigested food material in the feces, and undoubtedly accounts, in part at least, for the low value for available energy noted with some of these men. And yet it is a fact that, using the two illustrations cited in discussing the nitrogen data, *Gar* and *Mon* on December 10 to 15, when the energy of the food with each subject was about 3,000 calories, there is actually a slightly larger value for available energy in the case of *Mon*, although *Gar* had no bran and *Mon* had 168 grams. While this discrepancy is strikingly opposed to the general belief that the presence of bran in the diet would tend to lower the available energy, and one must realize that, after all, a relatively small proportion of bran is indigestible,[1] nevertheless bran was in most instances an added food and contained a definite amount of unhydrolyzable material. It would thus normally be expected to lower the energy available. In practically all studies on reduced diet low values for available energy are found. Those noted here are well within normal limits and we have no reason to question the influence of the restricted diet upon the digestive processes of these men.

One great difficulty, encountered in this research, was the tendency for the reduced diet to produce constipation, this making the separation of feces difficult. With *Pec*, whose abnormal defecation has been commented on frequently in this report, no accurate separation could be obtained between November 29 and December 10, although three or four attempts were made, and only approximate values are recorded in table 55. (See p. 334.)

DIGESTION EXPERIMENT WITH SQUAD B ON GREATLY REDUCED DIET.

Examining the data in table 37, we find that the energy of the food per day with Squad A averaged not far from 2,000 calories after the first week. With Squad B, it will be recalled, the energy of the food was cut down on the average to not far from 1,500 calories, and it was possible so to adjust the food intake that practically all 12 men received the same amounts of energy and nitrogen. The digestion period extended from January 15 to 23 (nearly twice as long as most of the digestion periods with Squad A). This long period gave an admirable opportunity for a satisfactory separation and for a study as to what proportion of nitrogen and total energy will appear in the feces when identically the same amounts of food materials are passed through 12 different digestive tracts. The data for Squad B are given in table 38, from which it can be seen that the nitrogen per day in the food varied only from 7.34 grams to 8.54 grams, with an average of 8.21 grams. The nitrogen in the feces varied from 0.53 gram to 1.40 grams, with an average of 0.89 gram. It is perhaps of significance that the

[1] Street, Conn. Agr. Expt. Sta. Ann. Rep., 1914, p. 243.

TABLE 38.—*Nitrogen utilized and energy available from food in digestion period with reduced diet—Squad B.*

Date and subject.	Nitrogen per day—		Nitrogen utilized.		Energy per day—			Net energy.	
	(*a*) In food.	(*b*) In feces.	(*c*) Total (*a-b*).	(*d*) Per cent $\frac{(c \times 100)}{a}$.	(*e*) In food.	(*f*) In feces.	(*g*) In urine.	(*h*) Total $[e-(f+g)]$	(*i*) Per cent $\frac{(h \times 100)}{e}$
Jan. 15–23, 1918:	*gm.*	*gm.*	*gm.*		*cals.*	*cals.*	*cals.*	*cals.*	
Fis.........	8.32	1.40	6.92	83	1,550	145	78	1,327	86
Har.........	7.99	0.74	7.25	91	1,488	96	88	1,304	88
How.........	8.21	0.84	7.37	90	1,535	110	91	1,334	87
Ham.........	7.34	0.53	6.81	93	1,433	79	87	1,267	88
Kim.........	8.49	0.88	7.61	90	1,586	120	73	1,393	88
Lon.........	8.23	0.63	7.60	92	1,535	91	79	1,365	89
Sch.........	8.32	0.88	7.44	89	1,556	117	79	1,360	87
Liv.........	8.32	0.68	7.64	92	1,546	108	92	1,346	87
Sne.........	8.28	0.99	7.29	88	1,543	116	84	1,343	87
Tho.........	8.32	1.20	7.12	86	1,551	138	86	1,327	86
Van.........	8.15	0.99	7.16	88	1,528	126	82	1,320	86
Wil.........	8.54	0.92	7.62	89	1,556	132	83	1,341	86
Average..	8.21	0.89	7.32	89	1,534	115	84	1,336	87

lowest value (0.53) appeared with *Ham*, who likewise had the lowest nitrogen intake. The so-called digestible nitrogen ranged from 6.81 to 7.64 grams, with an average of 7.32 grams. The nitrogen utilized varied only from 83 to 93 per cent, with an average of 89 per cent.

Special attention should be given to the fecal nitrogen, for we have here conditions which are exactly comparable to those of Professor Chittenden's earlier research.[1] In the 6-day digestion period with Professor Chittenden's soldiers from January 12 to 17, 1904, an average of 49.4 grams of nitrogen was ingested by each subject, while the nitrogen in feces varied from 4.45 to 12.10 grams, with wide variations from the average (8.46 grams) in a majority of cases. Similar irregularities were noted in the digestion period from February 29 to March 6, 1904, and likewise from March 28 to April 1, 1904, although in this latter period the agreement was much closer. These experiments of Chittenden strongly suggest a disturbance of digestion with low diet, and it is difficult to account for the irregularity of the values. With our squad of 12 men such abnormalities did not appear, even though the nitrogen intakes were actually somewhat lower than those in Professor Chittenden's study and in all probability the caloric requirements were somewhat similar. It thus can be stated that with a group of college students on a very greatly reduced diet, disturbances in the proportion of nitrogen utilized were not found. The availability of the energy was not far from that found with Squad A,

[1] Chittenden, Physiological economy in nutrition, New York, 1907 (first issue, 1904), p. 131; see, also, in this connection, Benedict, Am. Journ. Physiol., 1906, 16, p. 420.

being on the average 87 per cent. The agreement among the men was remarkably constant, the widest variation being from 86 to 89 per cent. These men used on the average 25 grams of bran per day. The uniformity of the figures, both for nitrogen and energy, indicate that with a group of 12 men the same amount of food passing through 12 different digestive tracts results in a strikingly uniform degree of absorption, even when an extraordinarily low diet is being taken.

URINE.

The collection of the entire 24-hour amount of urine from 12 or more subjects for a period of several months was for the most part very successfully carried out for Squad A, with the kind cooperation of these men. We have full data for these specimens of the volume, specific gravity, and total nitrogen. Obviously the most important factor is the total nitrogen. The nitrogen data appear in several places in this report, but it hardly seems justifiable to print the entire records of the specific gravity and the volume. We content ourselves, therefore, with giving a typical specimen of the urine records. (See table 39.) This shows the statistics for *Gul*, who collected the urine for almost every day of the entire experimental period, *i. e.*, September 27, 1917, to February 2, 1918. Since this subject remained at Springfield throughout the Christmas vacation, the records also include these days.

STATISTICAL RECORDS OF URINE FOR SQUAD A.

The influence of restricted diet upon the volume of urine is typically shown in table 39. With *Bro, Can, Gar, Gul, Mon, Pea, Pec,* and *Vea,* the volume of urine was materially reduced as a result of the restricted diet, but with *Kon, Moy,* and *Spe* no effect on the volume of urine was noted. With a single subject (*Tom*) there was a distinct tendency for the volume of urine to increase, but it did not exceed the normal limits. Occasionally very low volumes were found as, for example, those with *Gul,* on January 17–18, 18–19, and 20–21. The largest volumes were consistently voided by *Can,* who had the largest body weight and who made a practice of drinking unusually large amounts of water. Even in his case, however, the volume did not exceed the normal amount.

The specific gravity has only a secondary interest in that it gives a rough indication of the amount of total solids, and incidentally, the amount of total nitrogen. With many of the subjects the specific gravity tended to increase, this being true of *Bro, Gul, Mon, Pea, Pec,* and *Vea.* With *Can, Kon, Gar, Moy,* and *Tom* no consistent change in the specific gravity was observed. With *Spe* there was a tendency for the specific gravity to become reduced. The general picture is that outlined in table 39 which indicates a tendency for the specific gravity to increase with the reduction in diet.

TABLE 39.—*Statistics of urine for Gul, Squad A.*

Date.	Specific gravity.	Volume.[1]	Total nitrogen.	Date.	Specific gravity.	Volume.[1]	Total nitrogen.
1917.				1917.			
Normal diet:		*c.c.*	*gm.*	Reduced diet:		*c.c.*	*gm.*
Sept. 27–28...	....	1,655	10.31	Dec. 4–5...	1.041	780	13.37
Sept. 28–29...	....	1,505	10.17	Dec. 5–6...	1.034	775	....
Sept. 29–30...	....	1,145	9.44	Dec. 6–7...	1.033	670	8.86
Oct. 1–2....	....	1,010	12.97	Dec. 7–8...	1.038	840	10.74
Oct. 2–3....	1.023	1,225	12.47	Dec. 8–9...	1.030	710	9.22
Oct. 3–4....	1.024	1,190	12.35	Dec. 10–11...	1.032	975	9.11
Reduced diet:				Dec. 11–12...	1.034	840	9.53
Oct. 4–5....	1.017	1,580	12.31	Dec. 12–13...	1.038	800	11.28
Oct. 5–6....	1.012	2,050	11.46	Dec. 13–14...	1.037	785	11.92
Oct. 6–7....	1.016	1,660	10.30	Dec. 14–15...	1.029	820	10.07
Oct. 7–8....	1.013	2,025	10.02	Dec. 15–16...	1.027	970	9.45
Oct. 8–9....	1.019	1,420	12.16	Dec. 16–17...	1.031	665	....
Oct. 9–10....	1.019	1,950	....	Dec. 17–18...	1.040	870	12.10
Oct. 10–11....	1.015	2,095	12.94	Dec. 18–19...	1.016	1,575	13.01
Oct. 11–12....	1.020	1,235	11.75	Dec. 19–20...	1.022	820	10.35
Oct. 12–13....	1.018	1,560	12.73	Dec. 20–21...	1.040	620	8.73
Oct. 13–14....	....	1,095	11.11	Dec. 21–22...	1.041	820	7.58
Oct. 15–16....	1.013	1,570	9.47	Dec. 22–23...	1.043	740	7.92
Oct. 16–17....	1.023	1,175	13.26	Dec. 23–24...	1.036	820	9.75
Oct. 17–18...	1.015	1,560	12.40	Dec. 24–25...	1.035	1,300	13.56
Oct. 18–19....	1.024	1,115	13.71	Dec. 25–26...	1.040	1,240	14.66
Oct. 19–20....	1.024	1,000	11.31	Dec. 26–27...	1.040	1,020	11.54
Oct. 20–21....	1.023	1,140	12.01	Dec. 27–28...	1.040	840	8.63
Oct. 21–22....	1.024	820	8.86	Dec. 28–29...	1.037	820	9.85
Oct. 22–23....	1.016	1,270	10.62	Dec. 29–30...	1.031	1,420	11.20
Oct. 23–24....	1.018	1,490	10.98	Dec. 30–31...	1.036	1,020	10.49
Oct. 24–25....	1.025	1,385	12.21	Dec. 31–Jan.1.	1.040	820	9.02
Oct. 25–26....	1.027	735	9.78	1918.			
Oct. 26–27....	1.031	600	9.33	Jan. 1–2....	1.039	740	8.92
Oct. 27–28....	1.031	675	10.53	Jan. 2–3....	1.043	520	7.26
Oct. 29–30....	1.026	990	9.92	Jan. 3–4....	1.042	920	13.48
Oct. 30–31....	1.028	1,035	11.96	Jan. 4–5....	1.040	680	8.28
Oct. 31-Nov. 1.	1.027	770	10.90	Jan. 5–6....	1.039	540	7.03
Nov. 1–2...	1.028	930	11.52	Jan. 6–7....	1.036	420	7.23
Nov. 2–3...	1.031	860	11.25	Jan. 7–8....	1.032	540	10.24
Nov. 4–5...	1.030	760	10.21	Jan. 8–9....	1.033	630	10.27
Nov. 5–6...	1.029	895	10.98	Jan. 9–10....	1.029	860	9.90
Nov. 6–7...	1.029	925	9.85	Jan. 10–11....	1.030	650	9.31
Nov. 7–8...	1.038	690	9.25	Jan. 11–12....	1.020	955	9.39
Nov. 8–9...	1.029	830	9.39	Jan. 12–13....	1.026	700	8.71
Nov. 9–10...	1.030	580	6.98	Jan. 13–14....	1.031	625	6.53
Nov. 10–11...	1.032	540	9.11	Jan. 14–15....	1.029	970	7.99
Nov. 12–13...	1.030	890	8.60	Jan. 15–16....	1.031	575	7.47
Nov. 13–14...	1.031	810	9.52	Jan. 16–17....	1.031	540	7.74
Nov. 14–15...	1.032	825	11.39	Jan. 17–18....	1.027	395	6.08
Nov. 15–16...	1.037	680	11.04	Jan. 18–19....	1.037	390	9.06
Nov. 16–17...	1.030	720	10.90	Jan. 19–20....	1.034	470	10.57
Nov. 17–18...	1.031	760	10.87	Jan. 20–21....	1.035	420	8.31
Nov. 18–19...	1.030	720	9.35	Jan. 21–22....	1.031	540	7.99
Nov. 19–20...	1.028	1,110	10.51	Jan. 22–23....	1.034	490	8.11
Nov. 20–21...	1.030	895	9.25	Jan. 23–24....	1.023	900	8.02
Nov. 21–22...	1.031	885	10.01	Jan. 24–25....	1.022	705	7.71
Nov. 22–23...	1.031	810	8.99	Jan. 25–26....	1.018	1,280	9.57
Nov. 23–24...	1.038	385	6.13	Jan. 26–27....	1.013	1,560	9.85
Nov. 24–25...	1.021	860	11.00	Jan. 27–28....	1.034	1,050	8.62
Nov. 26–27...	1.033	675	7.48	Jan. 28–29....	1.033	930	9.27
Nov. 27–28...	1.041	705	9.56	Jan. 29–30....	1.012	1,755	8.93
Nov. 28–29...	1.037	630	7.16	Jan. 30–31....	1.019	1,355	8.86
Nov. 29–30...	1.039	470	5.59	Jan. 31–Feb.1.	1.021	1,390	7.95
Dec. 1–2...	1.040	455	3.90	Feb. 1–2...	1.031	990	8.28
Dec. 2–3...	1.035	570	4.70	Feb. 2–3...	1.025	890	6.69
Dec. 3–4...	1.035	380	5.51				

[1] Volumes represent mainly 24 hour samples; a number were computed to basis of 24 hours from samples covering 22½ to 25¾ hours. In two instances the samples were for 21½ and 26 hours respectively.

The total nitrogen excretion may first be considered simply as an index of the excretion of organic material. It can be seen from table 39 that with *Gul* the nitrogen excretion varied considerably from day to day. The maximum amount recorded for this subject on any day was 14.66 grams during the Christmas vacation; the minimum amount was the extraordinarily small quantity of 3.90 grams on December 1–2. In the beginning of the experiment there was considerable irregularity in the amount of nitrogen excreted, with a tendency for lower values to obtain subsequent to November 22. Yet there appears to be no definite correlation between the volume of urine, the specific gravity, and the total nitrogen excretion, nor do the other subjects show an approximation to regularity in such relationship. The nitrogen data for the other subjects will, however, be given in subsequent tables and discussed in that connection.

The general conclusion, therefore, which may be drawn from the urinary excretion of these subjects is that the reduced diet has a distinct tendency to lower somewhat the volume of urine and likewise a corresponding tendency to increase to some extent the specific gravity. This is more or less to be inferred from the fact that there was no profound alteration in the total amount of nitrogen excreted, and hence the smaller volume of urine was somewhat more concentrated. Little, if any, satisfactory discussion can be introduced here as to the fact that the lower volumes require somewhat less work of the kidneys, for it may be questioned whether or not the decrease in the work of excretion due to the smaller volumes would not in large part be compensated by the somewhat increased concentration of the urine. In any event the change is not sufficient to consider that this would have a material effect upon the general urinary output of these subjects, so far as specific gravity and the volume of urine are concerned.

NITROGEN INTAKE AND OUTPUT OF SQUAD A.

While the statistics for *Gul* show no consistently lower output of nitrogen, save perhaps subsequent to November 22, nevertheless even this change was not profound, and it seems advisable to consider how the low diet affected the squad as a whole. It has already been shown that the intake of nitrogen was not in all cases alike. In general, however, the average intake was not far from the same for the entire squad, both in total calories and in total nitrogen. This is shown more in detail in certain other tables.[1]

Although this is not the specific place to discuss the relationship between the intake and output of nitrogen, with special reference to the nitrogen balance, several features of the first 12 days of the experiment justify our reproducing here the figures for the total nitrogen in urine for this period and likewise for a period of 12 days from

[1] See tables 46 to 58, pp. 312 to 341.

December 5 to 18, when the squad was essentially on maintenance diet at the lower level. (See tables 41 and 43.) The nitrogen in the food for the first 10 days in the experiment and for December 5 to 18 are also given in tables 40 and 42. Considering the nitrogen in the urine during the first 12 days of the experiment (table 41), we find that fluctuations occur not only between different men, but that the same man shows differences from day to day. The lowest nitrogen output is almost invariably shown by *Tom*. The total nitrogen output per day for the 12 men averages not far from 145 to 150 grams for this period.

TABLE 40.—*Total nitrogen in food during first 10 days of experiment—Squad A.*

Subject.	Normal diet.[1]			Reduced diet.						
	Oct. 1.	Oct. 2.	Oct. 3.	Oct. 4.	Oct. 5.	Oct. 6.	Oct. 7.	Oct. 8.	Oct. 9.	Oct. 10.
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Bro....	14.63	14.93	15.54	10.46	11.85	10.87	9.24	13.98	12.36	12.35
Can....	15.59	14.93	15.54	10.46	11.85	10.87	9.26	13.82	12.21	12.19
Fre.....	15.53	14.93	15.54	10.46	11.85	10.87	9.49	13.82	12.25	11.52
Gar....	17.49	14.61	15.54	10.46	11.85	10.87	9.14	13.67	12.21	11.83
Gul....	16.25	14.93	15.54	10.46	11.85	10.87	9.67	13.82	12.21	12.50
Mon....	16.55	14.93	15.54	10.46	11.85	10.87	10.00	13.82	12.21	12.30
Moy...	14.98	14.93	15.54	10.46	11.85	10.87	8.61	13.82	12.05	12.19
Pea....	15.94	14.93	15.54	10.46	11.85	10.87	9.21	13.82	12.21	12.03
Pec....	16.51	14.93	15.54	10.46	11.85	10.87	9.65	13.98	12.21	13.13
Spe....	17.79	14.93	15.54	10.46	11.85	10.87	9.65	13.82	12.21	12.19
Tom...	14.63	14.93	15.17	10.46	11.85	10.87	8.89	13.82	12.05	12.35
Vea....	16.25	14.93	15.54	10.46	11.85	10.87	9.14	13.67	12.05	11.52
Av..	16.01	14.90	15.51	10.46	11.85	10.87	9.33	13.82	12.19	12.18

[1] Samples were not obtained of the diet on September 28 and 29.

TABLE 41.—*Total nitrogen in urine per 24 hours during first 12 days of experiment—Squad A.*

Subject.	Normal diet.					Reduced diet.						
	Sept. 28.	Sept. 29.	Oct. 1.	Oct. 2.	Oct. 3.	Oct. 4.	Oct. 5.	Oct. 6.	Oct. 7.	Oct. 8.	Oct. 9.	Oct. 10.
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Bro..	9.98	9.90	11.72	12.38	11.42	10.82	11.77	11.25	11.35	10.15	13.75	11.59
Can..	13.36	11.50	13.60	13.27	14.41	13.46	13.00	13.34	13.65	15.24	13.50	14.41
Fre..	12.40	10.40	12.02	14.29	12.40	11.53	11.86	11.66	12.53	12.16	10.34	12.16
Gar..	14.45	11.96	14.50	13.56	14.03	11.71	10.71	11.43	11.33	12.22	12.56	11.76
Gul..	10.17	8.97	12.97	12.47	12.35	12.31	11.46	10.09	10.02	12.16	......	12.94
Mon.	11.66	8.98	13.85	7.30	17.38	7.03	12.59	14.19	12.89	11.64	11.10	13.49
Moy.	10.06	6.28	10.97	13.36	12.64	12.65	11.41	12.18	10.27	10.57	11.43	11.57
Pea..	14.18	11.77	12.21	13.80	13.91	14.53	14.37	11.58	13.22	14.93	15.53	14.83
Pec..	15.62	13.41	12.89	14.64	11.54	13.44	13.44	11.80	15.13	12.15	13.94	15.18
Spe..	14.81	14.56	13.85	14.70	14.49	11.92	13.69	12.47	10.38	12.93	12.88	12.99
Tom.	5.30	5.87	8.78	9.98	10.22	9.24	9.57	9.90	9.14	9.25	10.73	11.04
Vea..	17.21	12.70	15.24	13.41	13.00	12.82	10.38	10.82	11.31	11.18	12.21	11.51
Av..	12.43	10.53	12.72	12.76	13.15	11.79	12.02	11.73	11.77	12.05	12.54	12.79

TABLE 42.—*Total nitrogen in food during 13 typical days after long diet restriction—Squad A.*

Subject.	Dec. 5.	Dec. 6.	Dec. 7.	Dec. 8.	Dec. 10.	Dec. 11.	Dec. 12.	Dec. 13.	Dec. 14.	Dec. 15.	Dec. 16.	Dec. 17.	Dec. 18.
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Bro........	8.97	9.48	7.69	9.75	8.23	14.63	11.89	9.89	8.97	10.98	9.64	14.71	13.44
Can........	10.97	11.61	9.14	11.95	11.33	17.04	14.70	12.64	12.22	18.31	12.74	14.34	14.36
Kon........	8.81	8.54	6.57	7.86	7.76	10.12	11.39	7.86	8.17	10.51	9.17	11.55	10.50
Gar........	8.62	8.88	8.65	11.46	10.35	16.73	13.90	13.26	11.74	18.31	12.74	13.96	13.06
Gul........	10.02	10.77	8.45	8.80	9.95	10.43	12.02	10.83	8.97	10.98	10.02	12.76	11.71
Mon........	10.02	10.81	9.90	11.46	11.60	17.67	15.01	13.10	12.22	13.32	12.92	15.63	15.11
Moy........	9.56	9.67	7.38	8.82	8.70	14.63	14.03	10.02	8.48	10.98	9.64	14.34	14.19
Pea........	11.75	12.55	9.90	11.28	11.75	14.14	15.01	13.10	12.22	13.80	13.40	16.01	15.11
Pec........	9.75	10.41	8.45	8.64	9.63	10.75	12.02	10.34	8.48	10.51	9.55	12.76	11.71
Spe........	12.22	12.08	7.84	9.32	9.67	17.35	14.39	7.79	.....	.....	.....	.....	.....
Tom........	8.19	8.54	5.23	7.86	5.16	6.52	7.44	9.40	8.17	10.03	8.13	11.73	10.87
Vea........	8.19	8.70	6.75	8.51	8.07	9.81	11.24	9.40	8.48	10.51	8.61	10.90	10.04
Av......	9.76	10.17	8.00	9.64	9.35	13.32	12.75	10.64	9.83	12.57	10.60	13.52	12.74

TABLE 43.—*Total nitrogen in urine per 24 hours during 12 typical days after long restricted diet—Squad A.*

Subject.	Dec. 5.	Dec. 6.	Dec. 7.	Dec. 8.	Dec. 10.	Dec. 11.	Dec. 12.	Dec. 13.	Dec. 14.	Dec. 15.	Dec. 17[1].	Dec. 18.
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Bro..	10.33	......	9.10	9.89	9.96	10.34	12.16	10.64	10.47	9.03	......	13.21
Can..	10.86	12.22	10.39	11.76	9.54	......	12.15	11.38	11.31	11.18	......	13.54
Kon.	15.68	17.35	13.18	14.15	10.31	11.03	14.03	14.67	9.88	11.54	12.75	11.99
Gar..	11.21	9.58	11.87	9.05	10.59	10.04	11.08	10.41	9.02	8.71	11.40	13.36
Gul..	......	8.86	10.74	8.85	9.11	9.53	11.28	11.92	10.07	9.45	12.10	13.01
Mon.	12.55	12.59	11.67	12.18	10.17	11.65	12.33	11.71	7.31	13.21	10.36	13.01
Moy.	11.59	10.58	9.86	10.07	8.84	10.83	10.59	11.27	......	9.37	11.75	13.29
Pea..	......	10.91	11.35	9.29	11.21	10.82	11.88	12.19	12.22	10.98	12.28	13.82
Pec..	12.40	11.55	11.35	10.17	13.28	9.67	10.90	11.51	10.21	......	10.76	11.67
Spe..	14.81	11.95	10.83	11.66	8.79	13.11	9.40	12.31	......	......	......	......
Tom.	6.92	8.71	6.47	7.54	8.93	6.41	7.78	9.53	8.17	......	10.20	6.27
Vea..	9.72	10.79	11.61	10.26	9.44	8.60	11.68	12.50	9.37	......	10.98	11.12
Av..	11.61	11.37	10.70	10.41	10.01	10.18	11.27	11.67	9.80	10.43	11.40	12.21

[1] The urine samples for December 16 were frozen in transit, and it was thus impossible to obtain the nitrogen output for this day.

The total nitrogen intake at this time (table 40) is of special interest, since it gives us an indication of the first reduction in diet, which took place on October 4. Prior to this, although the subjects were requested to eat as freely as they normally would, we find that the nitrogen intake was surprisingly uniform with all men on October 1, 2, and 3, when the men were on an unrestricted diet. It is clear that any difference in intake for these 10 days must have been in the non-protein food materials, for these men had essentially the same protein intake. Indeed, the daily intake for the individual men is almost exactly the same save on October 1. This comparison of data presents an interesting physiological study, however, inasmuch as we have

here 12 men, each of whom took practically the same daily amount of nitrogen as the others for a period of approximately 10 days, and yet the nitrogen excretion varied somewhat widely for the corresponding days. Thus, on October 9 *Pea* and *Tom*, with essentially the same nitrogen intake, *i. e.*, 12.21 and 12.05 grams, respectively, have a nitrogen output in the urine of 15.53 grams for *Pea* and 10.73 grams for *Tom*. The striking fall in the nitrogen intake for the whole squad on October 4, amounting to over 60 grams, was accompanied by a fall of 16 grams in the total nitrogen in the output. On the whole the nitrogen output for the 12 days is reasonably constant, although the nitrogen intake was greatly decreased after the first 3 days for which we have a record of the food.

Another point which should be brought out is the fact that the nitrogen of the intake was by no means definitely fixed each day, but depended somewhat upon the character of the food served generally to the men. Thus, we find a marked rise from an average of 9.33 grams on October 7 to 13.82 grams on October 8. This is a good illustration of the lack of positive control of nitrogen intake; in other words, the nitrogen intake was not predetermined.

If we examine the nitrogen excretion in the 12 days from December 5 to December 18 (table 43) we note again rather striking irregularities, which are even greater than those noted for the October excretion, minimum figures of about 6 grams appearing in several instances. On the other hand, we have but to examine the nitrogen intake on the corresponding dates (see table 42) to find somewhat wide variations, which may, in part, account for some of the variations in the nitrogen in the urine. These two sets of tables, however, give a fairly good picture of the differences in nitrogen intake and nitrogen excretion observed with Squad A prior to the reduction in the diet and again at the lower level when they had approximately a maintenance diet.

Disregarding the individual variations found on the different days and taking the averages for the group, we may consider the total nitrogen excretion per man per 24 hours as illustrated in these specimen tables. On the first 12 days of the experiment, that is, from September 28 to October 10, inclusive, we find the average nitrogen excretion to be 12.19 grams of nitrogen per day (see table 41). The averages for the individual days do not vary widely from this total average, the highest daily average being 13.15 grams on October 3 and the lowest average, singularly enough on September 29, 10.53 grams, this being the last day on which the diet was uncontrolled, for the feeding at the diet table was not begun until the morning of October 1. Taken as a squad, therefore, the urinary excretion is surprisingly uniform.

The average daily excretion of nitrogen for the squad in the later period of the experiment, namely, from December 5 to December

18, inclusive, when the subjects had approximately a maintenance ration, at least so far as caloric intake was concerned, is shown in table 43. The average nitrogen excretion for the entire 12 days was 10.92 grams per man per day. The variations in daily averages are somewhat larger than in the earlier part of the experiment, for here they range from 9.80 grams on December 14 to a maximum of 12.21 grams 3 days later, but are reasonably uniform, the average value, 10.92 grams, being a little over 1 gram less than the average value found for the first 12 days of the research. In other words, we see clearly that we deal with no large variations in the daily excretion of nitrogen, considering the squad as a whole.

The average nitrogen intake in the food from October 1 to 10 inclusive (table 40) was 12.71 grams, although on 3 days high values were observed. The average of the first 3 days is 15.47 grams; the average of the last 7 days is 11.53 grams. The irregularity of the intake of nitrogen, even after the curtailment in the diet began, is shown by the fact that on October 7 the average nitrogen intake was 9.33 grams and on the next day it was 4.5 grams larger. Notwithstanding these relatively large variations in the nitrogen intake, the average urinary nitrogen (table 41) remained singularly constant throughout this period.

The nitrogen in the food intake in the period from December 5 to 18 is shown in table 42. Considerable variation is also found in these amounts, the daily averages ranging from the low value of 8 grams on December 7 to a maximum of 13.52 grams on December 17. The minimum average of 8 grams is 3 grams lower than the general average of 10.99 grams, and the maximum average is 2.5 grams higher. Turning again to the urinary output during this period (table 43), it is perhaps surprising that we find a greater degree of uniformity obtaining, for while there are variations, they do not approximate in size the variations found in the food intake. The fact that the average nitrogen intake in the period of December 5 to December 18 is 10.99 grams and the average nitrogen output in the urine is 10.92 grams shows that these men were not in nitrogen equilibrium, for no allowance has been made for fecal nitrogen or for losses through the skin. So while these subjects were in weight equilibrium, they were not as yet in nitrogen equilibrium. Mention is made of this here to emphasize the fact that while nitrogen equilibrium may suggest weight equilibrium, the reverse is by no means true. (See page 353.)

The inspection of the fragmentary evidence of the nitrogen intake and output, as shown in these sections of the food and urine tables for the two periods of the experiment, makes it necessary to present in abstract form the average nitrogen in the food and urine per man per day for the entire experimental period, for the relationship between them is an important one. Tables 40 to 43, inclusive, give not only the average values, but likewise the values for each man, and permit a study

of the variations found between individuals and between the results for the same individual from day to day. Of greater importance, however, is the picture presented by the squad as a whole. This is shown in table 44, in which is recorded the total nitrogen in the food and in the urine for the entire series, expressed as the average per man per day, for Squad A. An examination of the nitrogen in the urine shows, on the whole, a constant nitrogen output. It is rarely that differences of more than 2 grams are noted from day to day. Values less than 10 grams do not appear until November 9–10. An absolute minimum of 7.90 grams is noted on January 15–16. There is no clear picture of a definite appreciable reduction in the nitrogen output per man per day until approximately the middle of January, but in the latter part of January low figures appear with considerable frequency. In general one may state that in spite of the great alterations in the diet made with these men, the nitrogen excretion on the average was but little affected. If we average the low-diet values by months, we would find that the average excretion for the month of October would be 11.47 grams, for the month of November 10.60 grams, for the 3 weeks in December 10.87 grams, and for the month of January 10.34 grams.

The most important aim in the reduction of diet was to secure a decrease in caloric content and no attempt was made to secure an especially low level of protein. In fact, in certain instances, at least, the protein was measurably increased, since it was found that the low diet was resulting in a somewhat heavy draft upon body nitrogen. The nitrogen intake is also shown in table 44. After the first 3 days in October, the reduction in diet with special reference to the caloric content began. The irregularities of the nitrogen intake, as pointed out in the discussion of the two periods in tables 40 and 42, are likewise found throughout the entire period, practically no two days being alike. Occasionally, the variations are somewhat large as, for example, from October 17–18 to October 18–19, when there was an increase of nearly 4.5 grams. This again illustrates the fact that the protein was not controlled. With such variations in nitrogen intake, and particularly with the low nitrogen intake during a considerable period of the time, it is surprising that the urinary nitrogen was not more affected. Thus, for a period from October 31 to November 12, inclusive, the daily values for the nitrogen intake are all less than 10 grams; in fact most of them are less than 9 grams. Yet the nitrogen excretion in the urine remained at a fairly high level throughout the entire time, this being, of course, positive proof of a loss on the part of the squad as a whole of a considerable amount of body nitrogen.

The most important fact to be drawn from this table, therefore, is that in spite of material reductions in food nitrogen and relatively large variations in the intake of nitrogen, the urinary nitrogen output

remained singularly constant for the squad as a whole throughout practically the entire period, aside from the general slight change of 1 gram in level in the periods indicated above. The nitrogen in urine in the last week in October is essentially on the same level as the nitrogen in urine in the last week in January.

TABLE 44.—*Total nitrogen in food and urine*[1]—*Squad A.*

[Average per man per day.]

Date.	Total nitrogen in—		Date.	Total nitrogen in—		Date.	Total nitrogen in—	
	Food.	Urine.		Food.	Urine.		Food.	Urine.
1917.	*gm.*	*gm.*	1917.	*gm.*	*gm.*	1917.	*gm.*	*gm.*
Normal diet:			Reduced diet:			Reduced diet:		
Sept. 28–29	....	12.43	Nov. 5–6	9.26	10.98	Dec. 15–16	12.57	10.43
Sept. 29–30	....	10.53	Nov. 6–7	8.65	10.56	Dec. 16–17	10.60	....
Oct. 1–2	16.01	12.72	Nov. 7–8	9.56	10.94	Dec. 17–18	13.52	11.40
Oct. 2–3	14.90	12.76	Nov. 8–9	7.21	10.25	Dec. 18–19	12.74	12.21
Oct. 3–4	15.51	13.15	Nov. 9–10	7.90	9.17	Dec. 19–20	11.03	11.29
Reduced diet:			Nov. 10–11	8.93	11.21	Christmas		
Oct. 4–5	10.46	11.79	Nov. 12–13	7.94	9.33	recess.		
Oct. 5–6	11.85	12.02	Nov. 13–14	11.33	10.01	1918.		
Oct. 6–7	10.87	11.73	Nov. 14–15	10.72	11.29	Jan. 7–8	9.30	10.41
Oct. 7–8	9.33	11.77	Nov. 15–16	8.04	11.09	Jan. 8–9	10.53	9.99
Oct. 8–9	13.82	12.05	Nov. 16–17	10.40	11.89	Jan. 9–10	9.30	11.22
Oct. 9–10	12.19	12.54	Nov. 17–18	8.93	11.05	Jan. 10–11	8.18	11.21
Oct. 10–11	12.18	12.79	Nov. 18–19	8.63	10.73	Jan. 11–12	8.68	10.38
Oct. 11–12	10.89	11.16	Nov. 19–20	11.55	10.59	Jan. 12–13	8.67	10.82
Oct. 12–13	11.85	11.91	Nov. 20–21	10.58	10.68	Jan. 13–14	....	11.27
Oct. 13–14	9.29	10.95	Nov. 21–22	8.96	10.03	Jan. 14–15	6.94	9.06
Oct. 15–16	10.86	11.10	Nov. 22–23	9.73	9.99	Jan. 15–16	7.07	7.90
Oct. 16–17	12.59	12.23	Nov. 23–24	9.38	9.04	Jan. 16–17	9.24	9.49
Oct. 17–18	9.97	11.82	Nov. 24–25	9.41	10.32	Jan. 17–18	8.02	9.72
Oct. 18–19	14.37	13.16	Nov. 26–27	10.81	8.93	Jan. 18–19	10.92	10.81
Oct. 19–20	9.92	11.38	Nov. 27–28	8.87	10.13	Jan. 19–20	9.28	10.57
Oct. 20–21	10.17	11.92	Nov. 28–29	7.34	10.79	Jan. 20–21	8.85	10.25
Oct. 21–22	9.54	10.53	Nov. 29–30	....	10.75	Jan. 21–22	9.06	9.63
Oct. 22–23	8.77	10.22	Thanksgiving			Jan. 22–23	10.93	10.63
Oct. 23–24	10.62	11.05	recess.			Jan. 23–24	9.63	10.72
Oct. 24–25	12.61	11.27	Dec. 3–4	6.94	9.21	Jan. 24–25	9.89	9.87
Oct. 25–26	7.93	10.09	Dec. 4–5	11.47	11.51	Jan. 25–26	10.09	9.66
Oct. 26–27	10.87	10.56	Dec. 5–6	9.76	11.61	Jan. 26–27	10.06	10.89
Oct. 27–28	8.67	10.90	Dec. 6–7	10.17	11.37	Jan. 27–28	8.80	11.47
Oct. 29–30	11.54	10.22	Dec. 7–8	8.00	10.70	Jan. 28–29	11.84	10.21
Oct. 30–31	11.89	11.99	Dec. 8–9	9.64	10.41	Jan. 29–30	14.12	10.68
Oct. 31–Nov. 1	8.94	11.16	Dec. 10–11	9.35	10.01	Jan. 30–31	10.87	9.96
Nov. 1–2	8.89	11.92	Dec. 11–12	13.32	10.18	Jan. 31–Feb. 1	16.29	11.80
Nov. 2–3	9.98	11.94	Dec. 12–13	12.75	11.27	Feb. 1–2	14.74	11.78
Nov. 3–4	8.45	11.43	Dec. 13–14	10.64	11.67	Feb. 2–3	9.10	9.77
Nov. 4–5	8.53	11.15	Dec. 14–15	9.83	9.80			

[1] The values in this table, except for January 13–14, represent only days when the diet was controlled and do not include the uncontrolled Sundays.

NORMAL URINARY NITROGEN OF A GROUP OF COLLEGE STUDENTS.

Although the first 5 values for the urinary nitrogen in table 44, which are also shown in table 41, may be taken to indicate the normal nitrogen output for the group of 12 men when they were on unrestricted

diet, the evidence is not absolutely clear, for it can be seen from table 40 that although the men were supposed to be eating in a perfectly normal manner, as a matter of fact they took absolutely the same amount of nitrogen on two of the three days recorded and nearly the same on the third day. Hence, we do not deal here with a true uncontrolled diet. The data are therefore somewhat defective in indicating the probable normal urinary excretion of the undergraduates of this college.

Immediately prior to placing Squad B upon restricted diet in January, urine was collected from these men for a period usually varying from 16½ to 27 hours, and the nitrogen excretion computed therefrom on the 24-hour basis. These data are given in the lower portion of table 45. The average value for the entire group, calculated on the 24-hour basis, was 13.14 grams. The average value for Squad A during the last 2 days in September, was 11.48 grams; for the first 3 days in October it was 12.88 grams. (See table 41.) The latter average is practically the same as that found in the fragmentary data with Squad B, *i. e.*, 13.14 grams.

At the conclusion of our experiment at Springfield it became evident that we should have further data regarding the probable normal urinary excretion. It was observed by all of us that the college men were well fed, apparently enjoyed their meals, had a great deal of physical exercise and were very busy men. In spite of the general tendency towards conservation of wheat products, it appeared not unlikely that these men might normally eat considerable quantities of protein. This was further emphasized to our minds by the fact that on the days of uncontrolled diet practically all of our subjects took rather liberal amounts of protein. Consequently Professor Elmer Berry was sufficiently interested to arrange with another group of 12 men, none of whom had served on either squad, for the daily collection of their entire urine for 4 days, *i. e.*, February 11 to 15, inclusive. These urines were sent to the Nutrition Laboratory and there analyzed. The results are given in the upper part of table 45, and show that the average for these 12 men in this time was 13.97 grams, a little more than that calculated for Squad B and approximately 1 gram more than was found for Squad A during the first 3 days in October. It is somewhat questionable, of course, to assume that exactly the same dietetic habits would obtain, so far as protein intake is concerned, in the middle of February as in the first week in October. Nevertheless, it is highly probable that the average nitrogen excretion of these men is not far from 13 grams per day. Consequently we may rightly infer from the examination of the data in table 44 that Squad A, while on the reduced diet, had a nitrogen excretion averaging not far from 10.5 to 11 grams, and hence was on a slightly lower nitrogen output per day than was the regular undergraduate body of the Y. M. C. A. College.

TABLE 45.—*Nitrogen excretion of International Y. M. C. A. College students during periods with normal diet.*

Subject.	Age.	Body-weight.	Height.	Nitrogen excretion on— Feb. 11–12.	Feb. 12–13.	Feb. 13–14.	Feb. 14–15.	Feb. 15–16.	Average.
	yrs.	*kg.*	*cm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Branin	24	63	170	10.49	13.99	13.59	13.30	15.94	13.46
Brown, I. E.	27	77	178	12.61	18.13	18.70	16.82	19.26	17.10
Davis	22	67	178	11.49	14.18	12.49	....	....	12.72
Dennis	23	82	183	20.53	11.85	11.23	15.44	12.62	14.33
Hodge	22	72	180	14.02	12.28	11.31	12.13	15.15	12.98
Landis	22	70	170	9.33	13.54	14.09	13.08	14.84	12.98
Lewis	27	77	183	12.77	19.76	15.94	15.15	19.54	16.63
Lyon	21	73	174	15.66	18.73	14.49	13.07	13.81	15.15
McKelvey	24	68	173	13.21	14.37	14.38	14.50	12.76	13.84
McKnight	21	73	178	11.25	14.30	15.23	14.84	10.99	13.32
Nickerson	26	60	163	10.75	9.50	12.28	....	10.81	10.84
Otto	25	73	175	12.58	13.01	14.71	16.20	14.79	14.26
Average	24	71	175	12.89	14.47	14.04	14.45	14.59	13.97

Subject. (Squad B.)	Nitrogen excretion on Jan. 7–8, 1918. Hours represented.	Amount.	Calculated to 24 hours.
		gm.	*gm.*
Fis	18	7.72	10.29
Har	16½	9.58	13.93
How	7½	5.75	18.40
Ham	23¾	14.80	14.96
Kim	17½	8.67	11.89
Sch	22¾	8.60	9.07
Liv	27	16.24	14.44
Sne	21¼	12.16	13.73
Tho	16½	9.03	13.13
Van	17½	7.68	10.53
Wil	20¼	11.99	14.21
Average	....	....	13.14

STATISTICS OF URINE FOR SQUAD B ON REDUCED DIET.

Since the purpose of placing Squad B upon restricted diet was somewhat different from that for Squad A and the reduction in diet was very much greater, the statistics of urine for this squad are not given special treatment in this discussion. The values for the nitrogen per 24 hours in urine and the corresponding amounts of nitrogen in the food are given in the nitrogen balance tables 59 to 70 in a subsequent section. It is only necessary to point out at this time that an inspection of these tables shows that in spite of the great curtailment of nitrogen intake of nearly one-half, the average nitrogen

output remained with singular persistency over 9.5 grams, there being but one exception. *Kim*, with the relatively low average body-weight of 61 kilograms, showed an average nitrogen excretion of 9.2 grams. Since all these men had practically the same nitrogen intake of not far from 8 grams (for no fluctuation in the nitrogen intake appeared in this short period which was at all comparable to the variations in nitrogen intake found with Squad A) the consistency and uniformity in nitrogen excretion are all the more remarkable and point immediately toward a very considerable nitrogen loss, which will be subsequently discussed. The wholly remarkable consistency of nitrogen excretion in the urine, irrespective of the nitrogen ingested, explains largely the singularly anomalous fact that the nitrogen excretion of the subjects in Squad A on the Mondays following the free Sundays was not materially affected by the relatively large nitrogen intake on these days. The two subjects in Squad A, *Gul* and *Pec*, who collected the urine during the Christmas recess, showed relatively little change in the nitrogen output as compared with their probable nitrogen intake. See tables 51*a* and 55*a*, pages 325 and 336. The uniformity of nitrogen excretion with extraordinarily large changes in nitrogen intake in the food is a point worthy of special emphasis.

THE NITROGEN BALANCE.

It was hoped that in this study both the nitrogen intake and the nitrogen output could be sufficiently controlled throughout the entire time so that a complete nitrogen balance could be obtained and at the end of the experimental period the exact nitrogen loss to the body could be determined in addition to the changes in body-weight. It was psychologically undesirable to restrict the men at every meal, and free days were thus occasionally permitted, with, however, certain suggestions as to restrictions which it was believed the men would more or less heed. As shown on page 270 (table 34), on the uncontrolled Sundays the food taken by the men contained much larger amounts of energy than they ordinarily consumed, often more than twice the amount, but the nitrogen intake was by no means so large proportionately. There were, of course, occasional exceptions, such as the 28.47 grams of nitrogen taken on January 13 by *Kon* and *Gul*, and 32.7 grams by *Moy*. But on the average the squad consumed on these uncontrolled days 16.62 grams of nitrogen, a value 50 per cent higher than that indicated for the average intake per man per day during the whole experimental period (10 grams). In addition to these uncontrolled Sundays we have likewise four days at the Thanksgiving recess of uncontrolled period and also a somewhat lengthy period of 18 days at Christmas time. These breaks were simply unavoidable.

Aside from these uncontrolled periods, the nitrogen in the food was determined every day. The urine was also collected with remarkable

fidelity on the part of the men and the nitrogen in the urine determined. Thus, we have sufficient data with Squad A to indicate the general picture of the nitrogen balance throughout the entire 4 months. With Squad B the conditions were much more satisfactory from the experimental standpoint. The men were on the diet for a period of only 20 days, there were no days of uncontrolled diet, and the balance between the nitrogen intake and the nitrogen output may be definitely determined.

In any final summation of the nitrogen balance for the period of 4 months during which the experiment continued, the nitrogen intake during these unrestricted Sundays and the holiday periods must be taken into account. On 5 uncontrolled Sundays the men made reasonably close estimates of the food taken. These records are given with the computed energy and nitrogen content in table 34. It might be assumed that the amounts of nitrogen ingested on the uncontrolled Sundays could be taken as an index of the nitrogen intake on the Thanksgiving and Christmas holidays, but it is by no means certain that this would be a legitimate assumption. From the reports of the men regarding their dietetic habits during these vacations, it is clear that the high rate of nitrogen ingestion on the uncontrolled Sundays was by no means continued through the entire vacation periods. The fact that the men were morally obligated to return to college at or near their last recorded weight certainly acted as a deterring influence upon excessive consumption. It does not, therefore, seem justifiable to us to assume an average intake of 16.62 grams of nitrogen for each day not specifically noted in our tables between September 27 and February 3.

It may be seen, however, that any nitrogen balance which may be made without taking into consideration the nitrogen intake of these days will undoubtedly be defective in that the apparent intake of nitrogen will be perceptibly lower than the real intake. On the other hand, the record of the output of nitrogen when measured by the nitrogen of the urine and feces is also deficient in that the urinary and fecal analyses take no note of the loss through the skin, perspiration, epithelial débris, growth of hair and nails, etc. Evidence with regard to the loss through the skin with normal individuals has been somewhat extensively discussed elsewhere.[1] In this earlier study it was found that on the average with men during complete muscular rest, living a restricted life inside the respiration calorimeter, about 0.1 gram of nitrogen per 24 hours was excreted through the skin. During severe muscular work with free perspiration the experimental data showed that there may be as much as 0.22 gram of nitrogen excreted per hour. As may be seen from the record of the physical activity of the men in

[1] Benedict, Journ. Biol. Chem., 1906, 1, p. 263.

the low-diet research, they were by no means at rest. A large number of them indulged in severe physical exercise, such as gymnasium work and running. Although Professor Johnson reports that in the 5-minute bicycle riding period the men in Squad A perspired very rarely and very slightly as compared with the men in Squad B, who were on normal diet, nevertheless it is unquestionably true that the gymnastic work these men engaged in, and their occasional trips to the swimming-pool, would cause a considerable loss of cutaneous nitrogenous material.

Attempts have been made by various writers to estimate the loss through the skin and through the growth of hair and nails. Thus, Taylor[1] summarizes that such loss of nitrogen can not be less than 0.3 gram per day on the average. With the greater average activity of our subjects, as compared with the activity of the ordinary individual, 0.4 gram per day would be a closer estimate of the loss of nitrogen in this way. Hence, it can be seen that, in each case, 0.4 gram per day should be added to the nitrogen outgo to obtain the true nitrogen balance. Since the whole research extended over 103 days, we have an excretion of probably not less than 40 grams of cutaneous nitrogen which is not considered in either the urinary or the fecal loss. This will, in large part, at least, compensate for the excess nitrogen taken on the uncontrolled days. Accordingly, since there is uncertainty both as to the actual amount of nitrogen taken on the uncontrolled days and the cutaneous excretion, it seems best for purposes of discussion to omit both factors and to make the assumption, which may fairly be challenged, that these two more or less offset each other. With this preliminary announcement, therefore, we may consider the nitrogen balance as computed from the determination of the nitrogen in food, feces, and urine.

A suggestion of great nitrogen losses appears in a previous section in a general comparison of the food intake and the nitrogen in urine, (see page 300) but no consideration was given to the nitrogen in feces. In the comparison given in this discussion, a more exact balance is made by allowing for the fecal nitrogen. These nitrogen balances are computed for each member of Squad A and combined in tabular form with the comparisons of the energy intake and output. The energy balances will be discussed later but are tabulated here for convenience. The great significance of the nitrogen balance makes it desirable, furthermore, to present all of the data in detail, and this is done in tables 46 to 58 for Squad A and in tables 59 to 70 for Squad B.

[1] Taylor, Digestion and metabolism, Philadelphia, 1912, p. 485.

NITROGEN BALANCE AND ENERGY AVAILABLE TO BODY, SQUAD A.

TABLE 46.—*Nitrogen balance and energy available to body*—GEORGE A. BROWN.

Date.	Nitrogen per 24 hours in— Food.	Feces.[1]	Urine.	Nitrogen balance.	Energy per 24 hours of— Food.	Feces.[1]	Urine. (N×8.0).	Net energy.
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	......	......	12.01	......	......	......	......	......
Sept. 28–29	......	......	9.98	......	......	......	......	......
Sept. 29–30	......	......	9.90	......	......	......	......	......
Sept. 30–Oct. 1	......	......	......	......	......	......	......	......
Oct. 1– 2	14.63	1.95	11.72	+ .96	3,300	166	94	3,040
Oct. 2– 3	14.93	1.95	12.38	+ .60	2,974	166	99	2,709
Oct. 3– 4	15.54	1.95	11.42	+2.17	3,656	166	91	3,399
Av. Oct. 1–4	15.03	......	11.84	......	......	......	......	3,049
Reduced diet:								
Oct. 4– 5	10.46	(1.75)	10.82	−2.11	2,288	(169)	87	2,032
Oct. 5– 6	11.85	(1.75)	11.77	−1.67	2,103	(169)	94	1,840
Oct. 6– 7	10.87	(1.75)	11.25	−2.13	2,529	(169)	90	2,270
Oct. 7– 8	9.24	(1.75)	11.35	−3.86	2,052	(169)	91	1,792
Oct. 8– 9	13.98	1.54	10.15	+2.29	2,391	171	81	2,139
Oct. 9–10	12.36	1.54	13.75	−2.93	2,212	171	110	1,931
Oct. 10–11	12.35	1.54	11.59	− .78	2,350	171	93	2,086
Oct. 11–12	10.96	1.54	9.89	− .47	2,335	171	79	2,085
Oct. 12–13	11.63	(1.13)	10.37	+ .13	2,556	(148)	83	2,325
Oct. 13–14	9.59	(1.13)	10.21	−1.75	2,281	(148)	82	2,051
Oct. 14–15	[2]15.13	......	......	......	[2,3]3,758	(148)	(86)	3,524
Av. Oct. 4–15	11.67	......	11.12	......	......	......	......	2,189
Oct. 15–16	10.50	(1.13)	11.13	−1.76	1,866	(148)	89	1,629
Oct. 16–17	12.29	(1.13)	11.77	− .61	2,026	(148)	94	1,784
Oct. 17–18	9.83	.72	11.22	−2.11	1,752	124	90	1,538
Oct. 18–19	14.30	.72	12.43	+1.15	2,497	124	99	2,274
Oct. 19–20	9.99	.72	10.02	− .75	1,721	124	80	1,517
Oct. 20–21	10.25	.72	11.50	−1.97	1,947	124	92	1,731
Oct. 21–22	9.71	(.73)	11.16	−2.18	2,369	(115)	89	2,165
Oct. 22–23	8.72	(.73)	9.44	−1.45	1,632	(115)	76	1,441
Oct. 23–24	10.84	(.73)	10.45	− .34	2,138	(115)	84	1,939
Oct. 24–25	12.48	(.73)	10.75	+1.00	2,306	(115)	86	2,105
Oct. 25–26	7.83	(.73)	8.80	−1.70	1,400	(115)	70	1,215
Oct. 26–27	10.78	(.73)	9.24	+ .81	2,046	(115)	74	1,857
Oct. 27–28	9.03	(.73)	9.34	−1.04	1,869	(115)	75	1,679
Oct. 28–29	[2]15.13	......	......	......	[3]3,758	(115)	(71)	3,572
Oct. 29–30	11.26	(.73)	8.36	+2.17	1,893	(115)	67	1,711
Av. Oct. 15–30	10.86	......	10.40	......	......	......	......	1,877
Oct. 30–31	11.59	(.73)	......	......	1,614	(115)	(75)	1,424
Oct. 31–Nov. 1	8.65	.73	10.21	−2.29	1,585	105	82	1,398
Nov. 1– 2	5.64	.73	9.36	−4.45	917	105	75	737
Nov. 2– 3	10.16	.73	11.27	−1.84	1,841	105	90	1,646
Nov. 3– 4	8.01	.73	11.68	−4.40	1,604	105	93	1,406
Nov. 4– 5	8.61	(.99)	11.37	−3.75	1,758	(133)	91	1,534

[1] In this table and in tables 47 to 70 the values in parentheses for nitrogen and energy in feces, are interpolated between determinations made in digestion periods. See table 37, p. 293.
[2] Assumed.
[3] Computed; see table 33, p. 269.

TABLE 46.—*Nitrogen balance and energy available to body*—GEORGE A. BROWN—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.[1]	Urine.		Food.	Feces.[1]	Urine. (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 5–6	9.59	(.99)	11.87	−3.27	1,460	(133)	95	1,232
Nov. 6–7	7.81	(.99)	9.95	−3.13	1,478	(133)	80	1,265
Nov. 7–8	8.88	(.99)	12.02	−4.13	1,819	(133)	96	1,590
Nov. 8–9	6.73	(.99)	9.47	−3.73	1,377	(133)	76	1,168
Nov. 9–10	8.44	(.99)	9.10	−1.65	1,477	(133)	73	1,271
Nov. 10–11	9.17	(.99)	12.45	−4.27	1,635	(133)	100	1,402
Nov. 11–12	[2]14.05	......	......	......	[2]3,951	(133)	(82)	3,736
Av. Oct. 30–Nov. 12	9.03	......	10.80	......	......	......	......	1,524
Nov. 12–13	8.06	1.24	8.00	−1.18	1,726	160	64	1,502
Nov. 13–14	11.66	1.24	10.63	− .21	1,949	160	85	1,704
Nov. 14–15	10.83	1.24	10.17	− .58	1,676	160	81	1,435
Nov. 15–16	7.85	1.24	11.47	−4.86	1,446	160	92	1,194
Nov. 16–17	9.94	1.24	10.37	−1.67	1,425	160	83	1,182
Nov. 17–18	9.14	1.24	10.16	−2.26	1,810	160	81	1,569
Nov. 18–19	7.50	(1.21)	10.05	−3.76	1,417	(153)	80	1,184
Nov. 19–20	11.22	(1.21)	10.81	− .80	2,143	(153)	86	1,904
Nov. 20–21	10.70	(1.21)	10.62	−1.13	1,827	(153)	85	1,589
Nov. 21–22	6.95	(1.21)	8.97	−3.23	1,540	(153)	72	1,315
Nov. 22–23	4.22	(1.21)	8.78	−5.77	1,428	(153)	70	1,205
Nov. 23–24	8.94	(1.21)	6.85	+ .88	1,884	(153)	55	1,676
Nov. 24–25	9.01	(1.21)	9.08	−1.28	1,704	(153)	73	1,478
Nov. 25–26	[2]16.13	......	......	......	[2]3,797	(153)	(75)	3,569
Nov. 26–27	10.76	(1.21)	9.44	+ .11	1,981	(153)	76	1,752
Nov. 27–28	8.31	(1.21)	8.90	−1.80	1,464	(153)	71	1,240
Nov. 28–29	6.64	(1.21)	9.33	−3.90	1,616	(153)	75	1,388
Av. Nov. 12–29	9.29	......	9.60	......	......	......	......	1,582
Nov. 29–30	......	......	10.02	......	......	......	......	......
Nov. 30–Dec. 1	......	......	7.65	......	......	......	......	......
Dec. 1–2	......	......	7.08	......	......	......	......	......
Dec. 2–3	......	......	11.36	......	......	......	......	......
Dec. 3–4	6.73	(1.21)	8.43	−2.91	1,349	(153)	67	1,129
Dec. 4–5	10.96	(1.21)	11.29	−1.54	1,879	(153)	90	1,636
Dec. 5–6	8.97	(1.21)	10.33	−2.57	1,858	(153)	83	1,622
Dec. 6–7	9.48	(1.21)	......	......	2,026	(153)	(78)	1,795
Dec. 7–8	7.69	(1.21)	9.10	−2.62	1,814	(153)	73	1,588
Dec. 8–9	9.75	(1.21)	9.89	−1.35	2,017	(153)	79	1,785
Dec. 9–10	[2]15.46	......	......	......	[2]4,152	(153)	(80)	3,919
Dec. 10–11	8.23	(1.21)	9.96	−2.94	2,080	(153)	80	1,847
Dec. 11–12	14.63	(1.21)	10.34	+3.08	3,003	(153)	83	2,767
Dec. 12–13	11.89	(1.21)	12.16	−1.48	2,337	(153)	97	2,087
Dec. 13–14	9.89	(1.21)	10.64	−1.96	2,044	(153)	85	1,806
Dec. 14–15	8.97	(1.21)	10.47	−2.71	2,235	(153)	84	1,998
Dec. 15–16	10.98	(1.21)	9.03	+ .74	2,764	(153)	72	2,539
Dec. 16–17	9.64	(1.21)	......	......	2,145	(153)	(89)	1,903
Dec. 17–18	14.71	(1.21)	......	......	2,621	(153)	(89)	2,379
Dec. 18–19	13.44	(1.21)	13.21	− .98	2,668	(153)	106	2,409
Dec. 19–20[3]	12.29	(1.21)	12.77	−1.69	2,586	(153)	102	2,331
Av. Dec. 3–20	10.81	......	10.59	......	......	......	......	2,091

[1] In this table and in tables 47 to 70 the values in parentheses for nitrogen and energy in feces are interpolated between determinations made in digestion periods. See table 37, p. 293.
[2] Computed; see table 33, p. 269.
[3] Dec. 20, 1917, to Jan. 7, 1918 (inclusive), Christmas recess.

TABLE 46.—*Nitrogen balance and energy available to body*—GEORGE A. BROWN—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.[1]	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Jan. 8– 9	8.85	(1.21)	7.03	+ .61	1,475	(153)	56	1,266
Jan. 9–10	8.15	(1.21)	9.05	−2.11	1,368	(153)	72	1,143
Jan. 10–11	4.14	(1.21)	9.87	−6.94	931	(153)	79	699
Jan. 11–12	7.21	(1.21)	10.11	−4.11	1,117	(153)	81	883
Jan. 12–13	8.46	(1.21)	10.39	−3.14	1,772	(153)	83	1,536
Jan. 13–14	[1]20.09	(1.21)	12.67	+6.21	[1]4,385	(153)	101	4,131
Jan. 14–15	2.72	1.18	6.35	−4.81	584	145	51	388
Jan. 15–16	4.81	1.18	6.22	−2.59	902	145	50	707
Av. Jan. 8–16	8.05	....	8.96	....	....	....	....	1,344
Jan. 16–17	10.47	1.18	9.79	− .50	1,941	145	78	1,718
Jan. 17–18	11.66	1.18	11.10	− .62	1,853	145	89	1,619
Jan. 18–19	11.32	1.18	10.71	− .57	1,947	145	86	1,716
Jan. 19–20	10.95	1.18	9.24	+ .53	2,256	145	74	2,037
Jan. 20–21	8.45	1.18	10.19	−2.92	1,781	145	82	1,554
Jan. 21–22	8.28	1.18	10.07	−2.97	1,435	145	81	1,209
Jan. 22–23	10.12	1.18	10.42	−1.48	1,663	145	83	1,435
Jan. 23–24	7.85	1.18	10.88	−4.21	1,647	145	87	1,415
Jan. 24–25	10.66	1.18	11.53	−2.05	2,046	145	92	1,809
Jan. 25–26	8.91	1.18	9.62	−1.89	1,964	145	77	1,742
Jan. 26–27	10.51	1.18	10.34	−1.01	2,155	145	83	1,927
Jan. 27–28	9.11	1.18	11.29	−3.36	1,741	145	90	1,506
Jan. 28–29	12.44	1.18	9.55	+1.71	2,278	145	76	2,057
Jan. 29–30	17.53	1.18	12.25	+4.10	3,100	145	98	2,857
Jan. 30–31	12.01	(1.18)	9.95	+ .88	2,731	(145)	80	2,506
Jan. 31–Feb. 1	19.83	(1.18)	15.23	+3.42	3,337	(145)	122	3,070
Feb. 1– 2	16.30	(1.18)	13.29	+1.83	2,959	(145)	106	2,708
Feb. 2– 3	10.46	(1.18)	12.68	−3.40	2,116	(145)	101	1,870
Av. Jan. 16–Feb. 3	11.49	....	11.01	....	....	....	....	1,931

[1] Computed; see table 33, p. 269.

TABLE 47.—*Nitrogen balance and energy available to body*—KENNETH B. CANFIELD.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	......	......	11.47	......	......	......	......	......
Sept. 28–29	......	......	13.36	......	......	......	......	......
Sept. 29–30	......	......	11.50	......	......	......	......	......
Sept. 30–Oct. 1	......	......	......	......	......	......	......	......
Oct. 1– 2	15.59	1.36	13.60	+ .63	3,471	134	109	3,228
Oct. 2– 3	14.93	1.36	13.27	+ .30	2,974	134	106	2,734
Oct. 3– 4	15.54	1.36	14.41	− .23	3,656	134	115	3,407
Av. Oct. 1–4	15.35	......	13.76	......	......	......	......	3,123
Reduced diet:								
Oct. 4– 5	10.46	(1.36)	13.46	−4.36	2,304	(141)	108	2,055
Oct. 5– 6	11.85	(1.36)	13.00	−2.51	2,119	(141)	104	1,874
Oct. 6– 7	10.87	(1.36)	13.34	−3.83	2,545	(141)	107	2,297
Oct. 7– 8	9.26	(1.36)	13.65	−5.75	2,089	(141)	109	1,839
Oct. 8– 9	13.82	1.35	15.24	−2.77	2,379	147	122	2,110
Oct. 9–10	12.21	1.35	13.50	−2.64	2,199	147	108	1,944
Oct. 10–11	12.19	1.35	14.41	−3.57	2,337	147	115	2,075
Oct. 11–12	11.03	1.35	12.09	−2.41	2,363	147	97	2,119
Oct. 12–13	12.39	(1.11)	13.14	−1.86	2,713	(130)	105	2,478
Oct. 13–14	9.47	(1.11)	12.10	−3.74	2,276	(130)	97	2,049
Oct. 14–15	[1]13.45	......	......	......	[1]3,088	(130)	(96)	2,862
Av. Oct. 4–15	11.55	......	13.39	......	......	......	......	2,155
Oct. 15–16	11.13	(1.11)	11.89	−1.87	1,990	(130)	95	1,765
Oct. 16–17	12.67	(1.11)	12.43	− .87	2,104	(130)	99	1,875
Oct. 17–18	10.14	.86	12.39	−3.11	1,826	113	99	1,614
Oct. 18–19	14.30	.86	13.99	− .55	2,505	113	112	2,280
Oct. 19–20	9.53	.86	11.45	−2.78	1,650	113	92	1,445
Oct. 20–21	9.94	.86	12.26	−3.18	1,897	113	98	1,686
Oct. 21–22	9.55	(.97)	10.56	−1.98	2,340	(126)	84	2,130
Oct. 22–23	8.72	(.97)	9.60	−1.85	1,640	(126)	77	1,437
Oct. 23–24	10.85	(.97)	10.10	− .22	2,317	(126)	81	2,110
Oct. 24–25	12.02	(.97)	10.94	+ .11	2,219	(126)	88	2,005
Oct. 25–26	7.68	(.97)	10.77	−4.06	1,355	(126)	86	1,143
Oct. 26–27	10.47	(.97)	8.92	+ .58	1,976	(126)	71	1,779
Oct. 27–28	8.25	(.97)	10.35	−3.07	1,716	(126)	83	1,507
Oct. 28–29	[2]13.45	......	......	......	[2]3,088	(126)	(75)	2,887
Av. Oct. 15–29	10.62	......	11.20	......	......	......	......	1,833
Oct. 29–30	10.95	(.97)	8.24	+1.74	1,835	(126)	66	1,643
Oct. 30–31	12.14	(.97)	10.63	+ .54	1,676	(126)	85	1,465
Oct. 31–Nov. 1	8.97	1.07	12.22	−4.32	1,750	138	98	1,514
Nov. 1– 2	8.89	1.07	12.42	−4.60	1,454	138	99	1,217
Nov. 2– 3	10.08	1.07	11.07	−2.06	1,945	138	89	1,718
Nov. 3– 4	8.33	1.07	10.72	−3.46	1,746	138	86	1,522
Nov. 4– 5	8.30	(1.16)	11.32	−4.18	1,779	(153)	91	1,535
Av. Oct. 29–Nov. 5	9.67	......	10.95	......	......	......	......	1,516

[1] Assumed. [2] Computed; see table 33, p. 269.

TABLE 47.—*Nitrogen balance and energy available to body*—KENNETH B. CANFIELD—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 5–6	8.97	(1.16)	11.16	−3.35	1,423	(153)	89	1,181
Nov. 6–7	9.95	(1.16)	11.08	−2.29	1,975	(153)	89	1,733
Nov. 7–8	10.40	(1.16)	11.22	−1.98	2,130	(153)	90	1,887
Nov. 8–9	8.41	(1.16)	10.48	−3.23	1,656	(153)	84	1,419
Nov. 9–10	9.97	(1.16)	11.36	−2.55	1,736	(153)	91	1,492
Nov. 10–11	10.70	(1.16)	11.77	−2.23	1,894	(153)	94	1,647
Nov. 11–12	[1]13.30	......	......	......	[1]3,229	(153)	(90)	2,986
Nov. 12–13	8.06	1.24	10.58	−3.76	1,726	168	85	1,473
Nov. 13–14	11.66	1.24	10.21	+ .21	1,909	168	82	1,659
Nov. 14–15	10.83	1.24	10.42	− .83	1,732	168	83	1,481
Nov. 15–16	8.09	1.24	11.38	−4.53	1,609	168	91	1,350
Av. Nov. 5–16	10.03	......	10.97	......	......	......	......	1,664
Nov. 16–17	12.60	1.24	13.82	−2.46	2,165	168	111	1,886
Nov. 17–18	10.70	1.24	12.89	−3.43	2,324	168	103	2,053
Nov. 18–19	10.08	(1.50)	9.92	−1.34	2,278	(200)	79	1,999
Nov. 19–20	12.85	(1.50)	......	......	2,702	(200)	(90)	2,412
Nov. 20–21	12.27	(1.50)	12.65	−1.88	2,281	(200)	101	1,980
Nov. 21–22	12.18	(1.50)	5.56	+5.12	2,735	(200)	44	2,491
Nov. 22–23	13.79	(1.50)	13.19	− .90	2,990	(200)	106	2,684
Nov. 23–24	12.52	(1.50)	10.99	+ .03	2,852	(200)	88	2,564
Nov. 24–25	11.10	(1.50)	11.42	−1.82	2,193	(200)	91	1,902
Nov. 25–26	[1]13.14	......	......	......	[1]3,347	(200)	(92)	3,055
Nov. 26–27	14.34	(1.50)	11.53	+1.31	2,993	(200)	92	2,701
Nov. 27–28	8.75	(1.50)	12.01	−4.76	1,610	(200)	96	1,314
Nov. 28–29	6.64	(1.50)	11.22	−6.08	1,568	(200)	90	1,278
Av. Nov. 16–29	11.61	......	11.38	......	......	......	......	2,178
Nov. 29–30[2]	......	......	11.38	......	......	......	......	......
Dec. 3–4	7.04	(1.50)	8.45	−2.91	1,435	(200)	68	1,167
Dec. 4–5	10.62	(1.50)	12.93	−3.81	1,840	(200)	103	1,537
Dec. 5–6	10.97	(1.50)	10.86	−1.39	2,223	(200)	87	1,936
Dec. 6–7	11.61	(1.50)	12.22	−2.11	2,503	(200)	98	2,205
Dec. 7–8	9.14	(1.50)	10.39	−2.75	2,237	(200)	83	1,954
Dec. 8–9	11.95	(1.50)	11.76	−1.31	2,575	(200)	94	2,281
Dec. 9–10	[3]13.14	......	......	......	[3]3,347	(200)	(85)	3,062
Dec. 10–11	11.33	1.76	9.54	+ .03	2,717	231	76	2,410
Dec. 11–12	17.04	1.76	......	......	3,460	231	(87)	3,142
Dec. 12–13	14.70	1.76	12.15	+ .79	3,040	231	97	2,712
Dec. 13–14	12.64	1.76	11.38	− .50	2,706	231	91	2,384
Dec. 14–15	12.22	1.76	11.31	− .85	2,937	231	90	2,616
Dec. 15–16	18.31	(1.76)	11.18	+5.37	4,634	(231)	89	4,314
Dec. 16–17	12.74	(1.76)	......	......	3,031	(231)	(99)	2,701
Dec. 17–18	14.34	(1.76)	......	......	2,792	(231)	(99)	2,462
Dec. 18–19	14.36	(1.76)	13.54	− .94	3,039	(231)	108	2,700
Dec. 19–20[4]	12.83	(1.76)	12.67	−1.60	2,899	(231)	101	2,567
Av. Dec. 3–20	12.65	......	11.41	......	......	......	......	2,479

[1] Computed; see table 33, p. 269.
[2] Nov. 30–Dec. 2 (inclusive), Thanksgiving recess.
[3] Assumed.
[4] Dec. 20, 1917–Jan. 6, 1918 (inclusive), Christmas recess.

TABLE 47.—*Nitrogen balance and energy available to body*—KENNETH B. CANFIELD—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Jan. 7–8	7.63	(1.76)	11.75	−5.88	1,282	(215)	94	973
Jan. 8–9	9.49	(1.76)	11.66	−3.93	1,590	(215)	93	1,282
Av. Jan. 7–9	8.56	....	11.71	....	....	....	....	1,128
Jan. 9–10	13.37	(1.76)	14.37	−2.76	2,414	(215)	115	2,084
Jan. 10–11	10.66	(1.76)	14.07	−5.17	2,087	(215)	113	1,759
Jan. 11–12	13.10	(1.76)	7.70	+3.64	2,078	(215)	62	1,801
Jan. 12–13	11.75	(1.76)	12.88	−2.89	2,364	(215)	103	2,046
Jan. 13–14	[1]17.54	(1.76)	13.82	+1.96	[1]3,964	(215)	111	3,638
Jan. 14–15	12.73	1.76	10.57	+ .40	2,325	215	85	2,025
Jan. 15–16	10.45	1.76	11.68	−2.99	1,841	215	93	1,533
Jan. 16–17	15.05	1.76	13.06	+ .23	2,828	215	104	2,509
Jan. 17–18	11.83	1.76	11.35	−1.28	1,929	215	91	1,623
Jan. 18–19	17.25	1.76	13.94	+1.55	3,022	215	112	2,695
Jan. 19–20	16.51	1.76	13.48	+1.27	3,353	215	108	3,030
Jan. 20–21	9.44	1.76	12.37	−4.69	2,018	215	99	1,704
Jan. 21–22	15.57	1.76	11.79	+2.02	2,682	215	94	2,373
Jan. 22–23	19.45	1.76	14.97	+2.72	3,298	215	120	2,963
Jan. 23–24	18.35	1.76	14.39	+2.20	3,919	215	115	3,589
Jan. 24–25	10.51	1.76	13.25	−4.50	2,056	215	106	1,735
Jan. 25–26	13.67	1.76	12.53	− .62	3,198	215	100	2,883
Jan. 26–27	11.49	1.76	12.32	−2.59	2,389	215	99	2,075
Jan. 27–28	8.75	1.76	14.13	−7.14	1,670	215	113	1,342
Jan. 28–29	21.55	1.76	14.18	+5.61	4,159	215	113	3,831
Jan. 29–30	17.27	1.76	13.17	+2.34	3,057	215	105	2,737
Jan. 30–31	11.47	(1.76)	12.42	−2.71	2,636	(215)	99	2,322
Jan. 31–Feb. 1	19.30	(1.76)	14.02	+3.52	3,234	(215)	112	2,907
Feb. 1–2	16.30	(1.76)	13.84	+ .70	2,959	(215)	111	2,633
Feb. 2–3	10.46	(1.76)	11.52	−2.82	2,132	(215)	92	1,825
Av. Jan. 9–Feb. 3	14.15	....	12.87	....	....	....	....	2,386

[1] Computed; see table 33, p. 269.

TABLE 48.—*Nitrogen balance and energy available to body*—LESTER F. FRETTER.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	....	....	11.83	....	....	....	....	....
Sept. 28–29	....	....	12.40	....	....	....	....	....
Sept. 29–30	....	....	10.40	....	....	....	....	....
Sept. 30–Oct. 1	....	....	....	....	....	....	....	....
Oct. 1–2	15.53	1.86	12.02	+1.65	3,408	154	96	3,158
Oct. 2–3	14.93	1.86	14.29	−1.22	2,974	154	114	2,706
Oct. 3–4	15.54	1.86	12.40	+1.28	3,656	154	99	3,403
Av. Oct. 1–4	15.33	....	12.90	....	....	....	....	3,089

TABLE 48.—*Nitrogen balance and energy available to body*—LESTER F. FRETTER—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine. (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Oct. 4–5	10.46	(1.71)	11.53	−2.78	2,296	(150)	92	2,054
Oct. 5–6	11.85	(1.71)	11.86	−1.72	2,111	(150)	95	1,866
Oct. 6–7	10.87	(1.71)	11.66	−2.50	2,537	(150)	93	2,294
Oct. 7–8	9.49	(1.71)	12.53	−4.75	2,074	(150)	100	1,824
Oct. 8–9	13.82	1.56	12.16	+ .10	2,371	145	97	2,129
Oct. 9–10	12.25	1.56	10.34	+ .35	2,183	145	83	1,955
Oct. 10–11	11.52	1.56	12.16	−2.20	2,205	145	97	1,963
Oct. 11–12	10.80	1.56	10.02	− .78	2,314	145	80	2,089
Oct. 12–13	10.48	(1.23)	12.22	−2.97	2,212	(114)	98	2,000
Oct. 13–14	8.60	(1.23)	9.99	−2.62	1,984	(114)	80	1,790
Oct. 14–15	......	......	......	......	......	(114)	(77)	[1]4,000
Av. Oct. 4–15	11.01	......	11.45	......	......	......	......	2,179
Oct. 15–16	10.73	(1.23)	9.30	+ .20	1,915	(114)	74	1,727
Oct. 16–17	11.98	(1.23)	11.95	−1.20	1,968	(114)	96	1,758
Oct. 17–18	9.38	.90	11.71	−3.23	1,677	82	94	1,501
Oct. 18–19	12.90	.90	12.55	− .55	2,228	82	100	2,046
Oct. 19–20	10.06	.90	10.89	−1.73	1,835	82	87	1,666
Oct. 20–21	9.47	.90	10.31	−1.74	1,802	82	82	1,638
Oct. 21–22	10.15	(.90)	10.08	− .83	2,653	(82)	81	2,490
Oct. 22–23	8.25	(.90)	8.81	−1.46	1,553	(82)	70	1,401
Oct. 23–24	10.98	(.90)	10.77	− .69	2,274	(82)	86	2,106
Oct. 24–25	11.36	(.90)	11.65	−1.19	2,119	(82)	93	1,944
Av. Oct. 15–25	10.53	......	10.80	......	......	......	......	1,828

[1] Estimate from diet of normal subjects.

TABLE 49.—*Nitrogen balance and energy available to body*—EVERETT R. KONTNER.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet:[1]								
Oct. 30–31	10.84	(.87)	15.48	−5.51	1,404	(125)	124	1,155
Oct. 31–Nov. 1	7.95	.87	10.81	−3.73	1,383	125	86	1,172
Nov. 1–2	8.64	.87	15.80	−8.03	1,336	125	126	1,085
Nov. 2–3	9.44	.87	13.35	−4.78	1,716	125	107	1,484
Nov. 3–4	10.12	.87	11.62	−2.37	1,861	125	93	1,643
Nov. 4–5	8.61	(.97)	11.75	−4.11	1,766	(138)	94	1,534
Nov. 5–6	9.59	(.97)	12.76	−4.14	1,476	(138)	102	1,236
Nov. 6–7	8.15	(.97)	11.72	−4.54	1,563	(138)	94	1,331
Nov. 7–8	8.88	(.97)	11.34	−3.43	1,819	(138)	91	1,590
Nov. 8–9	6.26	(.97)	10.39	−5.10	1,298	(138)	83	1,077
Nov. 9–10	7.05	(.97)	8.83	−2.75	1,233	(138)	71	1,024

[1] Estimates of the intake in the diets for Oct. 28–29 and Oct. 29–30 were as follows: Oct. 28–29, nitrogen, 12.34 gms.; energy, 2,377 cals.; Oct. 29–30, nitrogen, 18.26 gms.; energy, 3,641 cals.

TABLE 49.—*Nitrogen balance and energy available to body*—EVERETT R. KONTNER—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 10–11	8.70	(.97)	11.11	−3.38	1,548	(138)	89	1,321
Nov. 11–12	[1]18.36	......	......	......	[1]4,569	(138)	(91)	4,340
Nov. 12–13	6.65	1.06	11.61	−6.02	1,400	150	93	1,157
Nov. 13–14	10.75	1.06	11.01	−1.32	1,704	150	88	1,466
Nov. 14–15	9.47	1.06	11.68	−3.27	1,550	150	93	1,307
Nov. 15–16	8.01	1.06	11.74	−4.79	1,498	150	94	1,254
Nov. 16–17	8.52	1.06	13.03	−5.57	1,058	150	104	804
Nov. 17–18	8.50	1.06	12.08	−4.64	1,714	150	97	1,467
Nov. 18–19	8.19	(1.07)	12.06	−4.94	1,643	(150)	96	1,397
Nov. 19–20	10.91	(1.07)	10.04	− .20	2,133	(150)	80	1,903
Nov. 20–21	10.40	(1.07)	11.22	−1.89	1,738	(150)	90	1,498
Nov. 21–22	6.95	(1.07)	11.82	−5.94	1,596	(150)	95	1,351
Nov. 22–23	8.39	(1.07)	9.72	−2.40	1,842	(150)	78	1,614
Nov. 23–24	8.16	(1.07)	9.64	−2.55	1,755	(150)	77	1,528
Nov. 24–25	9.16	(1.07)	11.49	−3.40	1,741	(150)	92	1,499
Nov. 25–26	[1]24.01	......	......	......	[1]5,256	(150)	(94)	5,012
Nov. 26–27	6.36	(1.07)	11.86	−6.57	1,165	(150)	95	920
Nov. 27–28	9.40	(1.07)	12.06	−3.73	1,675	(150)	96	1,429
Nov. 28–29[2]	7.42	(1.07)	......	......	1,729	(150)	(96)	1,483
Av. Oct. 30–Nov. 29.	9.46	......	11.70	......	......	......	......	1,569
Dec. 3– 4	7.76	(1.07)	11.63	−4.94	1,471	(150)	93	1,228
Dec. 4– 5	11.12	(1.07)	15.51	−5.46	1,876	(150)	124	1,602
Dec. 5– 6	8.81	(1.07)	15.68	−7.94	1,750	(150)	125	1,475
Dec. 6– 7	8.54	(1.07)	17.35	−9.88	1,781	(150)	139	1,492
Dec. 7– 8	6.57	(1.07)	13.18	−7.68	1,509	(150)	105	1,254
Dec. 8– 9	7.86	(1.07)	14.15	−7.36	1,620	(150)	113	1,357
Dec. 9–10	[3]24.01	......	......	......	[3]5,256	(150)	(98)	5,008
Dec. 10–11	7.76	1.07	10.31	−3.62	1,954	150	82	1,722
Dec. 11–12	10.12	1.07	11.03	−1.98	2,019	150	88	1,781
Dec. 12–13	11.39	1.07	14.03	−3.71	2,229	150	112	1,967
Dec. 13–14	7.86	1.07	14.67	−7.88	1,491	150	117	1,224
Dec. 14–15	8.17	1.07	9.88	−2.78	2,068	150	79	1,839
Dec. 15–16	10.51	(1.07)	11.54	−2.10	2,668	(150)	92	2,426
Dec. 16–17	9.17	(1.07)	......	......	2,041	(150)	(97)	1,794
Dec. 17–18	11.55	(1.07)	12.75	−2.27	2,089	(150)	102	1,837
Dec. 18–19	10.50	(1.07)	11.99	−2.56	2,082	(150)	96	1,836
Dec. 19–20[4]	9.59	(1.07)	12.81	−4.29	2,179	(150)	102	1,927
Av. Dec. 3–20	10.08	......	13.10	......	......	......	......	1,869
1918.								
Jan. 12–13	8.14	(.88)	12.08	−4.82	1,746	(129)	97	1,520
Jan. 13–14	[1]28.47	(.88)	11.75	+15.84	[1]5,264	(129)	94	5,041
Jan. 14–15	3.90	(.88)	8.56	−5.54	922	(129)	68	725
Jan. 15–16	6.82	.88	8.48	−2.54	1,245	129	68	1,048
Jan. 16–17	6.19	.88	7.88	−2.57	1,177	129	63	985

[1] Computed; see table 33, p. 269.
[2] Nov. 29–Dec. 2 (inclusive), Thanksgiving recess.
[3] Assumed.
[4] Dec. 20, 1917–Jan. 11, 1918 (inclusive), Christmas recess.

TABLE 49.—*Nitrogen balance and energy available to body*—EVERETT R. KONTNER—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine. (N×8.0).	
1918—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Jan. 17–18	5.95	.88	7.84	−2.77	935	129	63	743
Jan. 18–19	6.30	.88	9.24	−3.82	1,084	129	74	881
Jan. 19–20	6.52	.88	10.46	−4.82	1,369	129	84	1,156
Jan. 20–21	8.11	.88	10.11	−2.88	1,687	129	81	1,477
Jan. 21–22	6.82	.88	8.75	−2.81	1,374	129	70	1,175
Jan. 22–23	8.29	.88	9.52	−2.11	1,159	129	76	954
Jan. 23–24	7.02	.88	11.47	−5.33	1,429	129	92	1,208
Jan. 24–25	8.43	.88	10.71	−3.16	1,506	129	86	1,291
Jan. 25–26	8.91	.88	10.94	−2.91	2,020	129	88	1,803
Jan. 26–27	8.71	.88	8.03	− .20	1,932	129	64	1,739
Jan. 27–28	8.75	.88	11.12	−3.25	1,694	129	89	1,476
Jan. 28–29	8.81	.88	9.43	−1.50	1,800	129	75	1,596
Jan. 29–30	11.25	.88	11.81	−1.44	2,126	129	94	1,903
Jan. 30–31	9.41	(.88)	8.26	+ .27	2,063	(129)	66	1,868
Jan. 31–Feb. 1	12.29	(.88)	10.93	+ .48	2,092	(129)	87	1,876
Feb. 1– 2	16.03	(.88)	13.10	+2.05	2,926	(129)	105	2,692
Feb. 2– 3	8.52	(.88)	10.57	−2.93	1,830	(129)	85	1,616
Av. Jan. 12–Feb. 3	9.26	....	10.05	....	....	....	....	1,581

TABLE 50.—*Nitrogen balance and energy available to body*—GREYSON C. GARDNER.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 28–29	....	....	14.45	....	....	....	....	....
Sept. 29–30	....	....	11.96	....	....	....	....	....
Sept. 30–Oct. 1	....	....	....	....	....	....	....	....
Oct. 1– 2	17.49	1.77	14.50	+1.22	3,723	145	116	3,462
Oct. 2– 3	14.61	1.77	13.56	− .72	2,817	145	108	2,564
Oct. 3– 4	15.54	1.77	14.03	− .26	3,656	145	112	3,399
Av. Oct. 1–4	15.88	....	14.03	....	....	....	....	3,142
Reduced diet:								
Oct. 4– 5	10.46	(1.55)	11.71	−2.80	2,304	(141)	94	2,069
Oct. 5– 6	11.85	(1.55)	10.71	− .41	2,119	(141)	86	1,892
Oct. 6– 7	10.87	(1.55)	11.43	−2.11	2,545	(141)	91	2,313
Oct. 7– 8	9.14	(1.55)	11.33	−3.74	2,062	(141)	91	1,830
Oct. 8– 9	13.67	1.33	12.22	+ .12	2,350	137	98	2,115
Oct. 9–10	12.21	1.33	12.56	−1.68	2,199	137	100	1,962
Oct. 10–11	11.83	1.33	11.76	−1.26	2,271	137	94	2,040
Oct. 11–12	10.49	1.33	12.34	−3.18	2,264	137	99	2,028
Oct. 12–13	11.63	(1.29)	12.45	−2.11	2,572	(122)	100	2,350
Oct. 13–14	9.36	(1.29)	11.54	−3.47	2,263	(122)	92	2,049
Oct. 14–15	[1]14.67	....	....	....	[1]3,403	(122)	(90)	3,191
Av. Oct. 4–15	11.47	....	11.81	....	....	....	....	2,167

[1] Assumed.

TABLE 50.—*Nitrogen balance and energy available to body*—GREYSON C. GARDNER—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Oct. 15–16	10.19	(1.29)	10.96	−2.06	1,808	(122)	88	1,598
Oct. 16–17	11.98	(1.29)	11.25	− .56	1,976	(122)	90	1,764
Oct. 17–18	9.38	1.25	12.04	−3.91	1,693	106	96	1,491
Oct. 18–19	13.99	1.25	12.90	− .16	2,455	106	103	2,246
Oct. 19–20	9.37	1.25	12.11	−3.99	1,629	106	97	1,426
Oct. 20–21	9.94	1.25	11.55	−2.86	1,889	106	92	1,691
Oct. 21–22	8.93	(1.16)	7.73	+ .04	2,232	(108)	62	2,062
Oct. 22–23	8.25	(1.16)	9.28	−2.19	1,513	(108)	74	1,331
Oct. 23–24	10.06	(1.16)	10.67	−1.77	2,001	(108)	85	1,808
Oct. 24–25	11.86	(1.16)	11.08	− .38	2,198	(108)	89	2,001
Oct. 25–26	7.21	(1.16)	9.99	−3.94	1,324	(108)	80	1,136
Oct. 26–27	10.31	(1.16)	10.36	−1.21	1,979	(108)	83	1,788
Oct. 27–28	8.09	(1.16)	10.22	−3.29	1,711	(108)	82	1,521
Oct. 28–29	[1]14.67	....	....	....	[1]3,403	(108)	(79)	3,216
Av. Oct. 15–29	10.30	....	10.78	....	....	....	....	1,791
Oct. 29–30	10.79	(1.16)	9.51	+ .12	1,822	(108)	76	1,638
Oct. 30–31	11.86	(1.16)	11.34	− .64	1,760	(108)	91	1,561
Oct. 31–Nov. 1	8.66	1.07	10.97	−3.38	1,708	109	88	1,511
Nov. 1– 2	8.89	1.07	10.19	−2.37	1,510	109	82	1,319
Nov. 2– 3	9.92	1.07	11.11	−2.26	1,940	109	89	1,742
Nov. 3– 4	8.25	1.07	9.82	−2.64	1,747	109	79	1,559
Nov. 4– 5	8.61	(1.03)	9.37	−1.79	1,885	(121)	75	1,689
Nov. 5– 6	9.28	(1.03)	9.27	−1.02	1,489	(121)	74	1,294
Nov. 6– 7	9.95	(1.03)	9.68	− .76	1,991	(121)	77	1,793
Nov. 7– 8	10.40	(1.03)	9.89	− .52	2,138	(121)	79	1,938
Nov. 8– 9	8.10	(1.03)	9.97	−2.90	1,654	(121)	80	1,453
Nov. 9–10	7.97	(1.03)	10.21	−3.27	1,446	(121)	82	1,243
Nov. 10–11	8.70	(1.03)	10.03	−2.36	1,607	(121)	80	1,406
Nov. 11–12	[1]23.63	....	....	....	[1]4,978	(121)	(75)	4,782
Av. Oct. 29–Nov. 12.	10.36	....	10.10	....	....	....	....	1,781
Nov. 12–13	7.59	.99	8.61	−2.01	1,687	132	69	1,486
Nov. 13–14	11.19	.99	8.77	+1.43	1,878	132	70	1,676
Nov. 14–15	10.83	.99	10.67	−. 83	1,732	132	85	1,515
Nov. 15–16	8.73	.99	9.70	−1.96	1,757	132	78	1,547
Nov. 16–17	10.28	.99	11.24	−1.95	1,786	132	90	1,564
Nov. 17–18	9.16	.99	9.60	−1.43	2,083	132	77	1,874
Nov. 18–19	8.06	(1.67)	9.83	−3.44	1,780	(204)	79	1,497
Nov. 19–20	10.91	(1.67)	7.09	+2.15	2,381	(204)	57	2,120
Nov. 20–21	10.25	(1.67)	10.87	−2.29	1,965	(204)	87	1,674
Nov. 21–22	9.64	(1.67)	10.26	−2.29	2,351	(204)	82	2,065
Nov. 22–23	11.55	(1.67)	10.61	− .73	2,508	(204)	85	2,219
Nov. 23–24	10.93	(1.67)	10.33	−1.07	2,517	(204)	83	2,230
Nov. 24–25	9.49	(1.67)	10.26	−2.44	1,946	(204)	82	1,660
Nov. 25–26	....	....	....	....	....	....	....	....
Nov. 26–27	....	....	....	....	....	....	....	....
Nov. 27–28	8.31	(1.67)	9.78	−3.14	1,512	(204)	78	1,230
Nov. 28–29[2]	6.64	(1.67)	12.14	−7.17	1,624	(204)	97	1,323
Av. Nov. 12–29	9.57	....	9.98	....	....	....	....	1,712

[1] Computed; see table 33, p. 269.
[2] Nov. 29–Dec. 2 (inclusive), Thanksgiving recess.

TABLE 50.—*Nitrogen balance and energy available to body*—GREYSON C. GARDNER—continued.

Date.	Nitrogen per 24 hours in— Food.	Feces.	Urine.	Nitrogen balance.	Energy per 24 hours of— Food.	Feces.	Urine (N×8.0).	Net energy.
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Dec. 3– 4	7.76	(1.67)	7.22	−1.13	1,615	(204)	58	1,353
Dec. 4– 5	10.62	(1.67)	10.52	−1.57	1,983	(204)	84	1,695
Dec. 5– 6	8.62	(1.67)	11.21	−4.26	1,824	(204)	90	1,530
Dec. 6– 7	8.88	(1.67)	9.58	−2.37	1,891	(204)	77	1,610
Dec. 7– 8	8.65	(1.67)	11.87	−4.89	2,020	(204))	95	1,721
Dec. 8– 9	11.46	(1.67)	9.05	+ .74	2,359	(204)	72	2,083
Dec. 9–10	[1]24.53	....	....	....	[1]4,561	(204)	(79)	4,278
Dec. 10–11	10.35	2.35	10.59	−2.59	2,413	275	85	2,053
Dec. 11–12	16.73	2.35	10.04	+4.34	3,442	275	80	3,087
Dec. 12–13	13.90	2.35	11.08	+ .47	2,865	275	89	2,501
Dec. 13–14	13.26	2.35	10.41	+ .50	2,942	275	83	2,584
Dec. 14–15	11.74	2.35	9.02	+ .37	2,817	275	72	2,470
Dec. 15–16	18.31	(2.35)	8.71	+7.25	4,634	(275)	70	4,289
Dec. 16–17	12.74	(2.35)	....	....	3,023	(275)	(81)	2,667
Dec. 17–18	13.96	(2.35)	11.40	+ .21	2,521	(275)	91	2,155
Dec. 18–19	13.06	(2.35)	13.36	−2.65	2,634	(275)	107	2,252
Dec. 19–20[2]	12.83	(2.35)	10.96	− .48	2,838	(275)	88	2,475
Av. Dec. 3–20	12.79	....	10.33	....	....	....	....	2,400
1918.								
Jan. 7– 8	7.44	(1.19)	11.68	−5.43	1,245	(136)	93	1,016
Jan. 8– 9	7.83	(1.19)	11.45	−4.81	1,341	(136)	92	1,113
Jan. 9–10	7.35	(1.19)	10.96	−4.80	1,268	(136)	88	1,044
Jan. 10–11	6.58	(1.19)	11.30	−5.91	1,249	(136)	90	1,023
Jan. 11–12	6.57	(1.19)	9.98	−4.60	1,025	(136)	80	809
Jan. 12–13	8.14	(1.19)	9.66	−2.71	1,730	(136)	77	1,517
Jan. 13–14	[1]15.34	(1.19)	15.14	− .99	[1]4,521	(136)	121	4,264
Jan. 14–15	7.46	1.19	9.13	−2.86	1,381	136	73	1,172
Jan. 15–16	3.60	1.19	7.52	−5.11	687	136	60	491
Jan. 16–17	7.05	1.19	9.47	−3.61	1,314	136	76	1,102
Jan. 17–18	3.89	1.19	8.34	−5.64	685	136	67	482
Av. Jan. 7–18	7.39	....	10.42	....	....	....	....	1,276
Jan. 18–19	10.68	1.19	10.70	−1.21	1,904	136	86	1,682
Jan. 19–20	6.70	1.19	8.89	−3.38	1,467	136	71	1,260
Jan. 20–21	11.39	1.19	11.57	−1.37	2,406	136	93	2,177
Jan. 21–22	7.64	1.19	8.90	−2.45	1,400	136	71	1,193
Jan. 22–23	9.48	1.19	9.80	−1.51	1,580	136	78	1,366
Jan. 23–24	5.39	1.19	8.97	−4.77	1,164	136	72	956
Jan. 24–25	8.08	1.19	9.00	−2.11	1,662	136	72	1,454
Jan. 25–26	11.79	1.19	8.37	+2.23	2,562	136	67	2,359
Jan. 26–27	10.73	1.19	9.75	− .21	2,230	136	78	2,016
Jan. 27–28	8.03	1.19	11.59	−4.75	1,566	136	93	1,337
Jan. 28–29	12.17	1.19	10.02	+ .96	2,245	136	80	2,029
Jan. 29–30	14.64	1.19	9.42	+4.03	2,757	136	75	2,546
Jan. 30–31	11.66	(1.19)	9.56	+ .91	2,494	(136)	76	2,282
Jan. 31–Feb. 1	19.03	(1.19)	12.47	+5.37	3,212	(136)	100	2,976
Feb. 1– 2	10.21	(1.19)	9.94	− .92	2,261	(136)	80	2,045
Feb. 2– 3	10.19	(1.19)	9.37	− .37	2,082	(136)	75	1,871
Av. Jan. 18–Feb. 3	10.49	....	9.90	....	....	....	....	1,847

[1] Computed; see table 33, p. 269. [2] Dec. 20, 1917–Jan. 6, 1918 (inclusive), Christmas recess.

TABLE 51.—*Nitrogen balance and energy available to body*—OTTO A. GULLICKSON.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	......	......	10.31	......	......	......	......	......
Sept. 28–29	......	......	10.17	......	......	......	......	......
Sept. 29–30	......	......	8.97	......	......	......	......	......
Sept. 30–Oct. 1	......	......	......	......	......	......	......	......
Oct. 1– 2	16.25	1.13	12.97	+2.15	3,525	107	104	3,314
Oct. 2– 3	14.93	1.13	12.47	+1.33	2,974	107	100	2,767
Oct. 3– 4	15.54	1.13	12.35	+2.06	3,656	107	99	3,450
Av. Oct. 1 to 4	15.57	......	12.60	......	......	......	......	3,177
Reduced diet:								
Oct. 4– 5	10.46	(1.05)	12.31	−2.90	2,304	(124)	98	2,082
Oct. 5– 6	11.85	(1.05)	11.46	− .66	2,119	(124)	92	1,903
Oct. 6– 7	10.87	(1.05)	10.09	− .27	2,545	(124)	81	2,340
Oct. 7– 8	9.67	(1.05)	10.02	−1.40	2,092	(124)	80	1,888
Oct. 8– 9	13.82	.96	12.16	+ .70	2,379	140	97	2,142
Oct. 9–10	12.21	.96	......	......	2,199	140	(101)	1,958
Oct. 10–11	12.50	.96	12.94	−1.40	2,395	140	104	2,151
Oct. 11–12	10.96	.96	11.75	−1.75	2,351	140	94	2,117
Oct. 12–13	11.94	(.99)	12.73	−1.78	2,630	(145)	102	2,383
Oct. 13–14	9.81	(.99)	10.77	−1.95	2,338	(145)	86	2,107
Oct. 14–15	[1]14.01	......	......	......	[1]3,671	(145)	(81)	3,445
Av. Oct. 4–15	11.65	......	11.58	......	......	......	......	2,229
Oct. 15–16	10.81	(.99)	9.47	+ .35	1,940	(145)	76	1,719
Oct. 16–17	12.98	(.99)	13.26	−1.27	2,170	(145)	106	1,919
Oct. 17–18	10.36	1.01	12.40	−3.05	1,867	149	99	1,619
Oct. 18–19	14.75	1.01	13.71	+ .03	2,596	149	110	2,337
Oct. 19–20	10.31	1.01	11.31	−2.01	1,795	149	90	1,556
Oct. 20–21	11.03	1.01	12.01	−1.99	2,091	149	96	1,846
Oct. 21–22	9.87	(.94)	8.86	+ .07	2,406	(139)	71	2,196
Oct. 22–23	9.19	(.94)	10.62	−2.37	1,687	(139)	85	1,463
Oct. 23–24	11.00	(.94)	10.98	− .92	2,183	(139)	88	1,956
Oct. 24–25	13.26	(.94)	12.21	+ .11	2,458	(139)	98	2,221
Oct. 25–26	8.15	(.94)	9.78	−2.57	1,498	(139)	78	1,281
Oct. 26–27	12.03	(.94)	9.33	+1.76	2,281	(139)	75	2,067
Oct. 27–28	9.18	(.94)	10.32	−2.08	1,906	(139)	83	1,684
Oct. 28–29	[2]14.01	......	......	......	[2]3,671	(139)	(81)	3,451
Av. Oct. 15–29	11.21	......	11.10	......	......	......	......	1,951
Oct. 29-30	12.51	(.94)	9.92	+1.65	2,140	(139)	79	1,922
Oct. 30–31	12.96	(.94)	11.96	+ .06	1,970	(139)	96	1,735
Oct. 31–Nov. 1	9.60	.87	11.01	−2.28	1,882	129	88	1,665
Nov. 1– 2	9.52	.87	11.52	−2.87	1,586	129	92	1,365
Nov. 2– 3	10.55	.87	11.13	−1.45	1,969	129	89	1,751
Nov. 3– 4	8.33	.87	......	......	1,683	129	(86)	1,468
Nov. 4– 5	8.61	(.89)	10.21	−2.49	1,774	(128)	82	1,564
Nov. 5– 6	9.59	(.89)	10.98	−2.28	1,476	(128)	88	1,260
Nov. 6– 7	6.47	(.89)	9.85	−4.27	1,267	(128)	79	1,060
Nov. 7– 8	7.34	(.89)	9.25	−2.80	1,488	(128)	74	1,286
Nov. 8– 9	7.04	(.89)	9.39	−3.24	1,443	(128)	75	1,240
Nov. 9–10	3.99	(.89)	6.98	−3.88	882	(128)	56	698
Nov. 10–11	7.66	(.89)	8.57	−1.80	1,470	(128)	69	1,273
Nov. 11–12	[1]14.01	......	......	......	[1]3,671	(128)	(69)	3,474
Av. Oct. 29–Nov. 12.	9.16	......	10.06	......	......	......	......	1,554

[1] Assumed. [2] Computed; see table 33, p. 269.

TABLE 51.—*Nitrogen balance and energy available to body*—OTTO A. GULLICKSON—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 12–13	8.37	.91	8.60	−1.14	1,800	127	69	1,604
Nov. 13–14	11.66	.91	9.52	+1.23	1,925	127	76	1,722
Nov. 14–15	10.83	.91	11.39	−1.47	1,692	127	91	1,474
Nov. 15–16	7.85	.91	11.04	−4.10	1,485	127	88	1,270
Nov. 16–17	9.78	.91	10.90	−2.03	1,444	127	87	1,230
Nov. 17–18	8.67	.91	10.87	−3.11	1,779	127	87	1,565
Nov. 18–19	8.95	(1.23)	9.35	−1.63	1,820	(177)	75	1,568
Nov. 19–20	11.86	(1.23)	10.51	+ .12	2,296	(177)	84	2,035
Nov. 20–21	11.65	(1.23)	9.25	+1.17	1,998	(177)	74	1,747
Nov. 21–22	11.04	(1.23)	10.01	− .20	2,375	(177)	80	2,118
Nov. 22–23	9.45	(1.23)	8.99	− .77	2,092	(177)	72	1,843
Nov. 23–24	2.48	(1.23)	6.13	−4.88	1,008	(177)	49	782
Nov. 24–25	8.88	(1.23)	10.78	−3.13	1,649	(177)	86	1,386
Nov. 25–26	[1]14.05	......	......	......	[1]4,830	(177)	(73)	4,580
Nov. 26–27	8.79	(1.23)	7.48	+ .08	1,604	(177)	60	1,367
Nov. 27–28	7.95	(1.23)	9.56	−2.84	1,489	(177)	76	1,236
Nov. 28–29	7.73	(1.23)	7.16	− .66	1,787	(177)	57	1,553
Av. Nov. 12–29	9.41	......	9.47	......	......	......	......	1,711
Nov. 29–30	......	......	5.59	......	......	......	......	......
Nov. 30–Dec. 1	......	......	......	......	......	......	......	......
Dec. 1– 2	......	......	3.90	......	......	......	......	......
Dec. 2– 3	......	......	4.70	......	......	......	......	......
Dec. 3– 4	3.68	(1.23)	5.51	−3.06	755	(177)	44	534
Dec. 4– 5	12.34	(1.23)	13.37	−2.26	2,174	(177)	107	1,890
Dec. 5– 6	10.02	(1.23)	......	......	2,003	(177)	(89)	1,737
Dec. 6– 7	10.77	(1.23)	8.86	+ .68	2,276	(177)	71	2,028
Dec. 7– 8	8.45	(1.23)	10.74	−3.52	1,832	(177)	86	1,569
Dec. 8– 9	8.80	(1.23)	8.85	−1.28	1,790	(177)	71	1,542
Dec. 9–10	[1]14.95	......	......	......	[1]5,355	(177)	(72)	5,106
Dec. 10–11	9.95	1.54	9.11	− .70	2,335	226	73	2,036
Dec. 11–12	10.43	1.54	9.53	− .64	2,037	226	76	1,735
Dec. 12–13	12.02	1.54	11.28	− .80	2,353	226	90	2,037
Dec. 13–14	10.83	1.54	11.92	−2.63	2,186	226	95	1,865
Dec. 14–15	8.97	1.54	10.07	−2.64	2,243	226	81	1,936
Dec. 15–16	10.98	(1.54)	9.45	− .01	2,756	(226)	76	2,454
Dec. 16–17	10.02	(1.54)	......	......	2,179	(226)	(87)	1,866
Dec. 17–18	12.76	(1.54)	12.10	− .88	2,289	(226)	97	1,966
Dec. 18–19	11.71	(1.54)	13.01	−2.84	2,282	(226)	104	1,952
Dec. 19–20[2]	9.97	(1.54)	9.55	−1.12	2,134	(226)	76	1,832
Av. Dec. 3–20	10.39	......	10.24	......	......	......	......	2,005
1918.								
Jan. 5– 6	0.00	(1.05)	7.03	−8.08	0,000	(152)	56	−208
Jan. 6– 7	0.00	(1.05)	8.07	−9.12	0,000	(152)	65	−217
Jan. 7– 8	7.95	(1.05)	10.24	−3.34	1,657	(152)	82	1,423
Jan. 8– 9	14.18	(1.05)	10.27	+2.86	2,712	(152)	82	2,478
Jan. 9–10	7.83	(1.05)	9.90	−3.12	1,343	(152)	79	1,112
Jan. 10–11	7.22	(1.05)	9.31	−3.14	1,349	(152)	74	1,123
Jan. 11–12	7.53	(1.05)	9.39	−2.91	1,174	(152)	75	947
Jan. 12–13	8.46	(1.05)	8.36	− .95	1,796	(152)	67	1,577
Av. Jan. 5–13	6.65	......	9.07	......	......	......	......	1,083

[1] Computed; see table 33, p. 269. [2] Dec. 20, 1917–Jan. 6, 1918 (inclusive), Christmas recess.

TABLE 51.—*Nitrogen balance and energy available to body*—OTTO A. GULLICKSON—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine. (N ×8.0).	
1918—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Jan. 13–14	[1]28.47	(1.05)	6.81	+20.61	[1]5,264	(152)	54	5,058
Jan. 14–15	7.78	1.05	7.99	−1.26	1,439	152	64	1,223
Jan. 15–16	5.46	1.05	7.47	−3.06	965	152	60	753
Jan. 16–17	6.35	1.05	7.74	−2.44	1,278	152	62	1,064
Jan. 17–18	0.00	1.05	6.08	−7.13	24	152	49	−177
Jan. 18–19	0.00	1.05	9.06	−10.11	24	152	72	−200
Jan. 19–20	8.46	1.05	10.57	−3.16	1,772	152	85	1,535
Jan. 20–21	5.73	1.05	8.31	−3.63	1,495	152	66	1,277
Jan. 21–22	6.82	1.05	7.99	−2.22	1,366	152	64	1,150
Jan. 22–23	8.10	1.05	8.11	−1.06	1,441	152	65	1,224
Jan. 23–24	6.36	1.05	8.02	−2.71	1,321	152	64	1,105
Jan. 24–25	9.04	1.05	7.71	+ .28	1,779	152	62	1,565
Jan. 25–26	8.96	1.05	9.57	−1.66	1,979	152	77	1,750
Jan. 26–27	10.51	1.05	9.46	±0.00	2,163	152	76	1,935
Jan. 27–28	9.62	1.05	9.00	− .43	2,421	152	72	2,197
Jan. 28–29	10.74	1.05	9.27	+ .42	2,002	152	74	1,776
Jan. 29–30	11.25	1.05	8.93	+1.27	2,086	152	71	1,863
Jan. 30–31	9.94	(1.05)	8.86	+ .03	2,174	(152)	71	1,951
Jan. 31–Feb. 1	12.55	(1.05)	7.95	+3.55	2,130	(152)	64	1,914
Feb. 1– 2	16.56	(1.05)	8.28	+7.23	3,001	(152)	66	2,783
Feb. 2– 3	8.52	(1.05)	6.83	+ .64	1,827	(152)	55	1,620
Av. Jan. 13–Feb. 3.	9.11	....	8.29	....	....	....	....	1,607

[1] Computed; see table 33, p. 269.

TABLE 51a.—*Nitrogen in urine during Christmas recess*—OTTO A. GULLICKSON.

Date.	Nitrogen in urine per 24 hours.	Date.	Nitrogen in urine per 24 hours.
1917.	*gm.*	1917.	*gm.*
Dec. 20–21	9.31	Dec. 28–29	9.85
Dec. 21–22	7.58	Dec. 29–30	11.20
Dec. 22–23	7.31	Dec. 30–31	10.49
Dec. 23–24	9.75	Dec. 31–Jan. 1	9.02
Dec. 24–25	13.56	1918.	
Dec. 25–26	14.66	Jan. 1– 2	8.92
Dec. 26–27	11.54	Jan. 2– 3	7.26
Dec. 27–28	8.63	Jan. 3– 4	13.48
		Jan. 4– 5	8.28

TABLE 52.—*Nitrogen balance and energy available to body*—KIRK G. MONTAGUE.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	......	......	12.27	......	......	......	......	......
Sept. 28–29	......	......	11.66	......	......	......	......	......
Sept. 29–30	......	......	8.98	......	......	......	......	......
Sept. 30–Oct. 1	......	......	......	......	......	......	......	......
Oct. 1– 2	16.55	1.59	13.85	+1.11	3,588	148	111	3,329
Oct. 2– 3	14.93	1.59	7.30	+6.04	2,974	148	58	2,768
Oct. 3– 4	15.54	1.59	17.38	−3.43	3,656	148	139	3,369
Av. Oct. 1–4	15.67	......	12.84	......	......	......	......	3,155
Reduced diet:								
Oct. 4– 5	10.46	(1.41)	7.03	+2.02	2,296	(142)	56	2,098
Oct. 5– 6	11.85	(1.41)	12.59	−2.15	2,111	(142)	101	1,868
Oct. 6– 7	10.87	(1.41)	14.19	−4.73	2,537	(142)	114	2,281
Oct. 7– 8	10.00	(1.41)	12.89	−4.30	2,123	(142)	103	1,878
Oct. 8– 9	13.82	1.22	11.64	+ .96	2,371	135	93	2,143
Oct. 9–10	12.21	1.22	11.10	− .11	2,191	135	89	1,967
Oct. 10–11	12.30	1.22	13.49	−2.41	2,350	135	108	2,107
Oct. 11–12	11.27	1.22	11.34	−1.29	2,401	135	91	2,175
Oct. 12–13	12.39	(1.23)	12.64	−1.48	2,705	(149)	101	2,455
Oct. 13–14	9.81	(1.23)	12.22	−3.64	2,322	(149)	98	2,075
Oct. 14–15	[1]12.29	......	......	......	[1]2,153	(149)	(90)	1,914
Av. Oct. 4–15	11.57	......	11.91	......	......	......	......	2,087
Oct. 15–16	11.13	(1.23)	10.24	− .34	1,982	(149)	82	1,751
Oct. 16–17	13.05	(1.23)	12.73	− .91	2,182	(149)	102	1,931
Oct. 17–18	10.36	1.24	10.62	−1.50	1,859	162	85	1,612
Oct. 18–19	14.75	1.24	12.02	+1.49	2,580	162	96	2,322
Oct. 19–20	9.99	1.24	10.44	−1.69	1,729	162	84	1,483
Oct. 20–21	10.41	1.24	12.58	−3.41	2,043	162	101	1,780
Oct. 21–22	9.71	(1.11)	8.83	− .23	2,377	(144)	71	2,162
Oct. 22–23	9.50	(1.11)	9.52	−1.13	1,737	(144)	76	1,517
Oct. 23–24	11.15	(1.11)	10.38	− .34	2,196	(144)	83	1,969
Oct. 24–25	13.26	(1.11)	8.73	+3.42	2,450	(144)	70	2,236
Oct. 25–26	8.46	(1.11)	9.99	−2.64	1,500	(144)	80	1,276
Oct. 26–27	10.62	(1.11)	10.32	− .81	2,013	(144)	83	1,786
Oct. 27–28	9.03	(1.11)	11.32	−3.40	1,869	(144)	91	1,634
Oct. 28–29	[2]12.29	......	......	......	[2]2,153	(144)	(95)	1,914
Oct. 29–30	12.04	(1.11)	12.39	−1.46	2,038	(144)	99	1,795
Oct. 30–31	12.64	(1.11)	11.90	− .37	1,896	(144)	95	1,657
Oct. 31–Nov. 1	9.60	.98	12.02	−3.40	1,866	126	96	1,644
Av. Oct. 15–Nov. 1.	11.06	......	10.88	......	......	......	......	1,792
Nov. 1– 2	9.52	.98	11.18	−2.64	1,570	126	89	1,355
Nov. 2– 3	10.55	.98	11.11	−1.54	1,961	126	89	1,746
Nov. 3– 4	8.33	.98	......	......	1,691	126	(89)	1,476
Nov. 4– 5	8.61	(1.16)	10.98	−3.53	1,774	(148)	88	1,538
Nov. 5– 6	9.59	(1.16)	10.99	−2.56	1,468	(148)	88	1,232
Nov. 6– 7	9.95	(1.16)	10.34	−1.55	1,904	(148)	83	1,673
Nov. 7– 8	10.40	(1.16)	10.74	−1.50	2,059	(148)	86	1,825
Nov. 8– 9	8.10	(1.16)	10.60	−3.66	1,567	(148)	85	1,334

[1] Assumed. [2] Computed; see table 33, p. 269.

TABLE 52.—*Nitrogen balance and energy available to body*—KIRK G. MONTAGUE—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 9–10	8.44	(1.16)	11.54	−4.26	1,485	(148)	92	1,245
Nov. 10–11	9.17	(1.16)	10.62	−2.61	1,643	(148)	85	1,410
Nov. 11–12	[1]8.77	......	......	......	[1]3,054	(148)	(83)	2,823
Nov. 12–13	8.37	1.33	10.08	−3.04	1,800	170	81	1,549
Nov. 13–14	11.66	1.33	10.57	− .24	1,917	170	85	1,662
Nov. 14–15	10.83	1.33	12.11	−2.61	1,684	170	97	1,417
Nov. 15–16	8.09	1.33	10.99	−4.23	1,586	170	88	1,328
Nov. 16–17	11.37	1.33	11.57	−1.53	1,949	170	93	1,686
Nov. 17–18	9.47	1.33	11.13	−2.99	2,054	170	89	1,795
Nov. 18–19	8.84	(1.74)	10.33	−3.23	1,909	(220)	83	1,606
Av. Nov. 1–19	9.45	......	10.93	......	......	......	......	1,594
Nov. 19–20	12.25	(1.74)	12.36	−1.85	2,597	(220)	99	2,278
Nov. 20–21	11.19	(1.74)	10.83	−1.38	2,123	(220)	87	1,816
Nov. 21–22	10.89	(1.74)	10.61	−1.46	2,535	(220)	85	2,230
Nov. 22–23	12.18	(1.74)	10.44	±0.00	2,497	(220)	84	2,193
Nov. 23–24	11.71	(1.74)	10.15	− .18	2,583	(220)	81	2,282
Nov. 24–25	8.88	(1.74)	11.47	−4.33	1,641	(220)	92	1,329
Nov. 25–26	[1]13.38	......	......	......	[1]4,660	(220)	(85)	4,355
Nov. 26–27	13.20	(1.74)	9.75	+1.71	2,493	(220)	78	2,195
Nov. 27–28	9.71	(1.74)	10.43	−2.46	1,724	(220)	83	1,421
Nov. 28–29	7.58	(1.74)	12.38	−6.54	1,750	(220)	99	1,431
Av. Nov. 19–29	11.10	......	10.94	......	......	......	......	2,153
Nov. 29–30[2]	......	......	12.34	......	......	......	......	......
Dec. 3– 4	9.16	(1.74)	17.40	−9.98	1,739	(220)	139	1,380
Dec. 4– 5	11.52	(1.74)	10.87	−1.09	1,996	(220)	87	1,689
Dec. 5– 6	10.02	(1.74)	12.55	−4.27	1,995	(220)	100	1,675
Dec. 6– 7	10.81	(1.74)	12.59	−3.52	2,255	(220)	101	1,934
Dec. 7– 8	9.90	(1.74)	11.67	−3.51	2,165	(220)	93	1,852
Dec. 8– 9	11.46	(1.74)	12.18	−2.46	2,319	(220)	97	2,002
Dec. 9–10	[1]12.39	......	......	......	[1]3,324	(220)	(89)	3,015
Av. Dec. 3–10	10.75	......	12.88	......	......	......	......	1,935
Dec. 10–11	11.60	2.14	10.17	− .71	2,613	269	81	2,263
Dec. 11–12	17.67	2.14	11.65	+3.88	3,576	269	93	3,214
Dec. 12–13	15.01	2.14	12.33	+ .54	3,098	269	99	2,730
Dec. 13–14	13.10	2.14	11.71	− .75	2,793	269	94	2,430
Dec. 14–15	12.22	2.14	7.31	+2.77	2,937	269	58	2,610
Dec. 15–16	13.32	(2.14)	13.21	−2.03	3,253	(269)	106	2,878
Dec. 16–17	12.92	(2.14)	......	......	2,826	(269)	(95)	2,462
Dec. 17–18	15.63	(2.14)	10.36	+3.13	3,084	(269)	83	2,732
Dec. 18–19	15.11	(2.14)	13.01	− .04	3,171	(269)	104	2,798
Dec. 19–20[3]	13.21	(2.14)	12.36	−1.29	2,973	(269)	99	2,605
Av. Dec. 10–20	13.98	......	11.35	......	......	......	......	2,672

[1] Computed; see table 33, p. 269.
[2] Nov. 30–Dec. 2 (inclusive), Thanksgiving recess.
[3] Dec. 20, 1917–Jan. 6, 1918 (inclusive), Christmas recess.

TABLE 52.—*Nitrogen balance and energy available to body*—KIRK G. MONTAGUE—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Jan. 7– 8[1]	13.56	(1.55)	10.60	+1.41	2,425	(188)	85	2,152
Jan. 8– 9	13.86	(1.55)	7.50	+4.81	2,676	(188)	60	2,428
Jan. 9–10	12.06	(1.55)	12.16	−1.65	2,005	(188)	97	1,720
Jan. 10–11	10.98	(1.55)	11.10	−1.67	2,128	(188)	89	1,851
Jan. 11–12	7.21	(1.55)	11.40	−5.74	1,125	(188)	91	846
Jan. 12–13	8.46	(1.55)	12.37	−5.46	1,788	(188)	99	1,501
Jan. 13–14	[2]15.80	(1.55)	10.71	+3.54	[2]3,955	(188)	86	3,681
Jan. 14–15	6.08	1.55	8.47	−3.94	1,240	188	68	984
Av. Jan. 7–15	11.00	......	10.54	......	......	......	......	1,895
Jan. 15–16	10.45	1.55	9.20	− .30	1,841	188	74	1,579
Jan. 16–17	9.99	1.55	9.19	− .75	1,828	188	74	1,566
Jan. 17–18	11.02	1.55	11.82	−2.35	1,762	188	95	1,479
Jan. 18–19	11.00	1.55	11.10	−1.65	1,914	188	89	1,637
Jan. 19–20	10.95	1.55	8.37	+1.03	2,264	188	67	2,009
Jan. 20–21	11.07	1.55	12.36	−2.84	2,348	188	99	2,061
Jan. 21–22	12.93	1.55	11.38	±0.00	2,218	188	91	1,939
Jan. 22–23	15.23	1.55	10.91	+2.77	2,683	188	87	2,408
Jan. 23–24	15.73	1.55	12.47	+1.71	3,327	188	100	3,039
Jan. 24–25	12.66	1.55	8.66	+2.45	2,145	188	69	1,888
Jan. 25–26	10.97	1.55	11.36	−1.94	2,330	188	91	2,051
Jan. 26–27	11.00	1.55	14.22	−4.77	2,261	188	114	1,959
Jan. 27–28	9.11	1.55	11.36	−3.80	1,749	188	91	1,470
Jan. 28–29	12.44	1.55	12.38	−1.49	2,262	188	99	1,975
Jan. 29–30	21.68	1.55	12.57	+7.56	3,768	188	101	3,479
Jan. 30–31	12.01	(1.55)	12.39	−1.93	2,719	(188)	99	2,432
Jan. 31– Feb. 1	19.83	(1.55)	11.92	+6.36	3,325	(188)	95	3,042
Feb. 1– 2	16.56	(1.55)	13.39	+1.62	2,977	(188)	107	2,682
Feb. 2– 3	8.61	(1.55)	9.43	−2.37	1,967	(188)	75	1,706
Av. Jan. 15–Feb. 3	12.80	......	11.29	......	......	......	......	2,126

[1] On Jan. 5 and 6 subject had no food. [2] Computed; see table 33, p. 269.

TABLE 53.—*Nitrogen balance and energy available to body*—HENRY A. MOYER.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	......	......	13.69	......	......	......	......	......
Sept 28–29	......	......	10.06	......	......	......	......	......
Sept. 29–30	......	......	6.28	......	......	......	......	......
Sept. 30–Oct. 1	......	......	......	......	......	......	......	......
Oct. 1– 2	14.98	1.51	10.97	+2.50	3,345	152	88	3,105
Oct. 2– 3	14.93	1.51	13.36	+ .06	2,974	152	107	2,715
Oct. 3– 4	15.54	1.51	12.64	+1.39	3,656	152	101	3,403
Av. Oct. 1–4	15.15	......	12.32	......	......	......	......	3,074

TABLE 53.—*Nitrogen balance and energy available to body*—HENRY A. MOYER—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine. (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Oct. 4– 5	10.46	(1.46)	12.65	−3.65	2,304	(157)	101	2,046
Oct. 5– 6	11.85	(1.46)	11.41	−1.02	2,119	(157)	91	1,871
Oct. 6– 7	10.87	(1.46)	12.18	−2.77	2,545	(157)	97	2,291
Oct. 7– 8	8.61	(1.46)	10.27	−3.12	2,031	(157)	82	1,792
Oct. 8– 9	13.82	1.41	10.57	+1.84	2,379	161	85	2,133
Oct. 9–10	12.05	1.41	11.43	− .79	2,170	161	91	1,918
Oct. 10–11	12.19	1.41	11.57	− .79	2,337	161	93	2,083
Oct. 11–12	10.65	1.41	11.30	−2.06	2,293	161	90	2,042
Oct. 12–13	10.91	(1.19)	8.96	+ .76	2,326	(146)	72	2,108
Oct. 13–14	8.60	(1.19)	9.86	−2.45	2,008	(146)	79	1,783
Oct. 14–15	[1]17.11	....	....	....	[1]3,971	(146)	(86)	3,739
Av. Oct. 4–15	11.56	....	11.02	....	....	....	....	2,164
Oct. 15–16	10.66	(1.19)	11.53	−2.06	1,911	(146)	92	1,673
Oct. 16–17	12.29	(1.19)	13.34	−2.24	2,042	(146)	107	1,789
Oct. 17–18	10.14	.96	10.80	−1.62	1,834	130	86	1,618
Oct. 18–19	14.53	.96	13.03	+ .54	2,554	130	104	2,320
Oct. 19–20	9.99	.96	10.09	−1.06	1,729	130	81	1,518
Oct. 20–21	10.41	.96	....	....	1,984	130	(89)	1,765
Oct 21–22	9.71	(1.04)	12.00	−3.33	2,377	(135)	96	2,146
Oct. 22–23	8.56	(1.04)	11.18	−3.66	1,579	(135)	89	1,355
Oct. 23–24	10.68	(1.04)	11.39	−1.75	2,117	(135)	91	1,891
Oct. 24–25	12.64	(1.04)	14.06	−2.46	2,343	(135)	112	2,096
Oct. 25–26	8.30	(1.04)	10.56	−3.30	1,527	(135)	84	1,308
Oct. 26–27	10.94	(1.04)	10.33	− .43	2,079	(135)	83	1,861
Oct. 27–28	8.87	(1.04)	12.09	−4.26	1,848	(135)	97	1,616
Oct. 28–29	[2]17.11	....	....	....	[2]3,971	(135)	(87)	3,749
Av. Oct. 15–29	11.06	....	11.70	....	....	....	....	1,908
Oct 29–30	11.26	(1.04)	9.68	+ .54	1,917	(135)	77	1,705
Oct. 30–31	11.74	(1.04)	11.88	−1.18	1,659	(135)	95	1,429
Oct. 31–Nov. 1	9.12	1.11)	11.38	−3.37	1,664	139	91	1,434
Nov. 1– 2	9.20	1.11	12.64	−4.55	1,489	139	101	1,249
Nov. 2– 3	9.76	1.11	13.27	−4.62	1,766	139	106	1,521
Nov. 3– 4	8.33	1.11	12.02	−4.80	1,675	139	96	1,440
Nov. 4– 5	8.61	(1.28)	12.42	−5.09	1,822	(157)	99	1,566
Nov. 5– 6	9.59	(1.28)	10.23	−1.92	1,476	(157)	82	1,237
Nov. 6– 7	8.15	(1.28)	11.02	−4.15	1,563	(157)	88	1,318
Nov. 7– 8	9.82	(1.28)	11.97	−3.43	2,017	(157)	96	1,764
Nov. 8– 9	6.26	(1.28)	9.35	−4.37	1,298	(157)	75	1,066
Nov. 9–10	7.81	(1.28)	9.80	−3.27	1,385	(157)	78	1,150
Nov. 10–11	8.70	(1.28)	11.41	−3.99	1,548	(157)	91	1,300
Nov. 11–12	[2]14.34	....	....	....	[2]3,948	(157)	(75)	3,716
Av. Oct. 29–Nov. 12.	9.48	....	11.31	....	....	....	....	1,564
Nov. 12–13	7.90	1.44	7.34	− .88	1,713	175	59	1,479
Nov. 13–14	11.66	1.44	10.67	− .45	1,973	175	85	1,713
Nov. 14–15	10.83	1.44	12.48	−3.09	1,692	175	100	1,417
Nov. 15–16	7.85	1.44	12.50	−6.09	1,485	175	100	1,210
Nov. 16–17	9.78	1.44	12.96	−4.62	1,404	175	104	1,125
Nov. 17–18	8.83	1.44	12.11	−4.72	1,768	175	97	1,496

[1] Assumed. [2] Computed; see table 33, p. 269.

TABLE 53.—*Nitrogen balance and energy available to body*—HENRY A. MOYER—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 18–19	8.19	(1.41)	12.03	−5.25	1,643	(171)	96	1,376
Nov. 19–20	10.75	(1.41)	11.03	−1.69	2,064	(171)	88	1,805
Nov. 20–21	10.07	(1.41)	10.52	−1.86	1,679	(171)	84	1,424
Nov. 21–22	6.63	(1.41)	6.43	−1.21	1,538	(171)	51	1,316
Nov. 22–23	8.04	(1.41)	9.87	−3.24	1,814	(171)	79	1,564
Nov. 23–24	8.01	(1.41)	9.89	−3.29	1,686	(171)	79	1,436
Nov. 24–25	8.54	(1.41)	11.55	−4.42	1,617	(171)	92	1,354
Nov. 25–26	[2]17.00	......	......	......	[2]4,763	(171)	(87)	4,505
Nov. 26–27	9.83	(1.41)	10.17	−1.75	1,815	(171)	81	1,563
Nov. 27–28	9.09	(1.41)	8.86	−1.18	1,617	(171)	71	1,375
Nov. 28–29	7.26	(1.41)	8.45	−2.60	1,740	(171)	68	1,501
Av. Nov. 12–29	9.43	......	10.43	......	......	......	......	1,627
Nov. 29–30	......	......	7.27	......	......	......	......	......
Nov. 30–Dec. 1	......	......	......	......	......	......	......	......
Dec. 1– 2	......	......	4.99	......	......	......	......	......
Dec. 2– 3	......	......	8.36	......	......	......	......	......
Dec. 3– 4	8.07	(1.41)	10.71	−4.05	1,537	(171)	86	1,280
Dec. 4– 5	11.24	(1.41)	11.14	−1.31	1,964	(171)	89	1,704
Dec. 5– 6	9.56	(1.41)	11.59	−3.44	1,917	(171)	93	1,653
Dec. 6– 7	9.67	(1.41)	10.58	−2.32	2,018	(171)	85	1,762
Dec. 7– 8	7.38	(1.41)	9.86	−3.89	1,693	(171)	79	1,443
Dec. 8– 9	8.82	(1.41)	10.07	−2.66	1,812	(171)	81	1,560
Dec. 9–10	[2]18.82	......	......	......	[2]4,795	(171)	(76)	4,548
Dec. 10–11	8.70	1.38	8.84	−1.52	2,104	167	71	1,866
Dec. 11–12	14.63	1.38	10.83	+2.42	3,019	167	87	2,765
Dec. 12–13	14.03	1.38	10.59	+2.06	2,773	167	85	2,521
Dec. 13–14	10.02	1.38	11.27	−2.63	2,043	167	90	1,786
Dec. 14–15	8.48	1.38	......	......	2,118	167	(83)	1,868
Dec. 15–16	10.98	(1.38)	9.37	+ .23	2,772	(167)	75	2,530
Dec. 16–17	9.64	(1.38)	......	......	2,153	(167)	(85)	1,901
Dec. 17–18	14.34	(1.38)	11.75	+1.21	2,579	(167)	94	2,318
Dec. 18–19	14.19	(1.38)	13.29	− .48	2,800	(167)	106	2,527
Dec. 19–20[1]	8.67	(1.38)	......	......	1,859	(167)	(106)	1,586
Av. Dec. 3–20	11.01	......	10.76	......	......	......	......	2,095
1918.								
Jan. 7– 8	......	......	11.93	......	......	......	......	......
Jan. 8– 9	8.85	(1.11)	9.87	−2.13	1,483	(148)	79	1,256
Jan. 9–10	7.83	(1.11)	16.37	−9.65	1,319	(148)	131	1,040
Jan. 10–11	7.22	(1.11)	13.03	−6.92	1,349	(148)	104	1,097
Jan. 11–12	7.21	(1.11)	11.27	−5.17	1,117	(148)	90	879
Jan. 12–13	8.14	(1.11)	12.54	−5.51	1,722	(148)	100	1,474
Av. Jan. 8–13	7.85	......	12.62	......	......	......	......	1,149
Jan. 13–14	[2]32.70	(1.11)	7.72	+23.87	[2]6,038	(148)	62	5,828
Jan. 14–15	8.10	1.11	13.58	−6.59	1,480	148	109	1,223
Jan. 15–16	6.82	1.11	7.78	−2.07	1,229	148	62	1,019
Jan. 16–17	7.69	1.11	9.62	−3.04	1,413	148	77	1,188
Jan. 17–18	6.27	1.11	11.76	−6.60	985	148	94	743
Jan. 18–19	11.32	1.11	11.54	−1.33	1,963	148	92	1,723

[1] Dec. 20, 1917–Jan. 6, 1918 (inclusive), Christmas recess.

[2] Computed; see table 33, p. 269.

TABLE 53.—*Nitrogen balance and energy available to body*—HENRY A. MOYER—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Jan. 19–20	10.45	1.11	14.72	−5.38	2,148	148	118	1,882
Jan. 20–21	7.36	1.11	10.38	−4.13	1,454	148	83	1,223
Jan. 21–22	9.97	1.11	11.75	−2.89	1,729	148	94	1,487
Jan. 22–23	10.12	1.11	14.34	−5.33	1,679	148	115	1,416
Jan. 23–24	7.85	1.11	12.20	−5.46	1,655	148	98	1,409
Jan. 24–25	11.04	1.11	9.52	+ .41	1,754	148	76	1,530
Av. Jan. 13–25	10.81	....	11.24	....	....	....	....	1,723
Jan. 25–26	10.97	1.11	7.96	+1.90	2,338	148	64	2,126
Jan. 26–27	8.71	1.11	15.94	−8.34	1,884	148	128	1,608
Jan. 27–28	8.75	1.11	13.12	−5.48	1,694	148	105	1,441
Jan. 28–29	10.74	1.11	11.68	−2.05	2,042	148	93	1,801
Jan. 29–30	11.25	1.11	7.04	+3.10	2,086	148	56	1,882
Jan. 30–31	9.68	(1.11)	9.46	− .89	2,116	(148)	76	1,892
Jan. 31–Feb. 1	19.36	(1.11)	12.60	+5.65	3,249	(148)	101	3,000
Feb. 1– 2	13.45	(1.11)	13.63	−1.29	2,491	(148)	109	2,234
Feb. 2– 3	8.52	(1.11)	6.77	+ .64	1,838	(148)	54	1,636
Av. Jan. 25–Feb. 3	11.27	....	10.91	....	....	....	....	1,958

TABLE 54.—*Nitrogen balance and energy available to body*—ALLEN S. PEABODY.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	....	....	16.24	....	....	....	....	....
Sept. 28–29	....	....	14.18	....	....	....	....	....
Sept. 29–30	....	....	11.77	....	....	....	....	....
Sept. 30–Oct. 1	....	....	....	....	....	....	....	....
Oct. 1– 2	15.94	1.39	12.21	+2.34	3,463	131	98	3,234
Oct. 2– 3	14.93	1.39	13.80	− .26	2,974	131	110	2,733
Oct. 3– 4	15.54	1.39	13.91	+ .24	3,656	131	111	3,414
Av. Oct. 1–4	15.47	....	13.31	....	....	....	....	3,127
Reduced diet:								
Oct. 4– 5	10.46	(1.31)	14.53	−5.38	2,304	(161)	116	2,027
Oct. 5– 6	11.85	(1.31)	14.37	−3.83	2,119	(161)	115	1,843
Oct. 6– 7	10.87	(1.31)	11.58	−2.02	2,545	(161)	93	2,291
Oct. 7– 8	9.21	(1.31)	13.22	−5.32	2,066	(161)	106	1,799
Oct. 8– 9	13.82	1.22	14.93	−2.33	2,379	191	119	2,069
Oct. 9–10	12.21	1.22	15.53	−4.54	2,199	191	124	1,884
Oct. 10–11	12.03	1.22	14.83	−4.02	2,308	191	119	1,998
Oct. 11–12	10.80	1.22	13.97	−4.39	2,322	191	112	2,019
Oct. 12–13	12.61	(1.11)	15.70	−4.20	2,754	(168)	126	2,460
Oct. 13–14	9.36	(1.11)	12.87	−4.62	2,239	(168)	103	1,968
Oct. 14–15	[1]17.60	....	....	....	[1]5,123	(168)	(103)	4,852
Av. Oct. 4–15	11.89	....	14.15	....	....	....	....	2,292

[1] Assumed.

TABLE 54.—*Nitrogen balance and energy available to body*—ALLEN S. PEABODY—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Oct. 15–16	11.13	(1.11)	12.80	−2.78	2,014	(168)	102	1,744
Oct. 16–17	13.05	(1.11)	13.98	−2.04	2,166	(168)	112	1,886
Oct. 17–18	10.14	.99	14.44	−5.29	1,818	145	116	1,557
Oct. 18–19	14.53	.99	15.46	−1.92	2,554	145	124	2,285
Oct. 19–20	9.84	.99	15.18	−6.33	1,716	145	121	1,450
Oct. 20–21	9.78	.99	13.54	−4.75	1,884	145	108	1,631
Oct. 21–22	9.55	(90)	13.05	−4.40	2,364	(140)	104	2,120
Oct. 22–23	8.87	(.90)	13.55	−5.58	1,677	(140)	108	1,429
Oct. 23–24	10.68	(.90)	13.80	−4.02	2,133	(140)	110	1,883
Oct. 24–25	13.26	(.90)	14.23	−1.87	2,466	(140)	114	2,212
Oct. 25–26	8.30	(.90)	12.61	−5.21	1,527	(140)	101	1,286
Oct. 26–27	10.94	(.90)	13.02	−2.98	2,087	(140)	104	1,843
Oct. 27–28	8.87	(.90)	12.18	−4.21	1,856	(140)	97	1,619
Oct. 28–29	[2]23.24	......	......	......	[2]7,537	(140)	(101)	7,296
Av. Oct. 15–29	11.58	......	13.68	......	......	......	......	2,160
Oct. 29–30	11.73	(.90)	13.13	−2.30	1,996	(140)	105	1,751
Oct. 30–31	12.64	(.90)	13.23	−1.49	1,896	(140)	106	1,650
Oct. 31–Nov. 1	9.60	.81	12.74	−3.95	1,882	135	102	1,645
Nov. 1– 2	9.20	.81	13.67	−5.28	1,528	135	109	1,284
Nov. 2– 3	10.55	.81	14.06	−4.32	2,064	135	112	1,817
Nov. 3– 4	8.33	.81	13.79	−6.27	1,778	135	110	1,533
Nov. 4– 5	8.61	(1.00)	12.98	−5.37	1,893	(149)	104	1,640
Nov. 5– 6	9.59	(1.00)	13.14	−4.55	1,555	(149)	105	1,301
Nov. 6– 7	9.95	(1.00)	12.51	−3.56	1,991	(149)	100	1,742
Nov. 7– 8	10.40	(1.00)	12 66	−3.26	2,170	(149)	101	1,920
Nov. 8– 9	8.41	(1.00)	11.60	−4.19	1,712	(149)	93	1,470
Nov. 9–10	10.21	(1.00)	10.52	−1.31	1,797	(149)	84	1,564
Nov. 10–11	8.64	(1.00)	10.06	−2.42	1,699	(149)	80	1,470
Nov. 11–12	[2]16.15	......	......	......	[2]4,522	(149)	(86)	4,287
Nov. 12–13	8.37	1.18	11.39	−4.20	1,840	163	91	1,586
Nov. 13–14	11.66	1.18	10.84	− .36	1,965	163	87	1,715
Nov. 14–15	10.83	1.18	10.69	−1.04	1,740	163	86	1,491
Nov. 15–16	8.09	1.18	10.77	−3.86	1,633	163	86	1,384
Av. Oct. 29–Nov. 16	10.16	......	12.22	......	......	......	......	1,736
Nov. 16–17	13.07	1.18	12.17	− .28	2,276	163	97	2,016
Nov. 17–18	10.70	1.18	13.00	−3.48	2,348	163	104	2,081
Nov. 18–19	10.39	(1.44)	12.06	−3.11	2,360	(211)	96	2,053
Nov. 19–20	13.63	(1.44)	11.92	+ .27	2,871	(211)	95	2,565
Nov. 20–21	12.08	(1.44)	11.72	−1.08	2,247	(211)	94	1,942
Nov. 21–22	12.62	(1.44)	11.02	+ .16	2,893	(211)	88	2,594
Nov. 22–23	10.72	(1.44)	9.03	+ .25	2,355	(211)	72	2,072
Nov. 23–24	12.64	(1.44)	6.78	+4.42	2,835	(211)	54	2,570
Nov. 24–25	10.62	(1.44)	11.21	−2.03	2,120	(211)	90	1,819
Nov. 25–26	[2]13.42	......	......	......	[2]3,310	(211)	(77)	3,022
Nov. 26–27	13.05	(1.44)	7.84	+3.77	2,551	(211)	63	2,277
Nov. 27–28	9.25	(1.44)	7.99	− .18	1,646	(211)	64	1,371
Nov. 28–29[1]	9.64	(1.44)	9.14	− .94	2,159	(211)	73	1,875
Av. Nov. 16–29	11.68	.....	10.32	......	......	......	......	2,174

[1] Nov. 29–Dec. 2 (inclusive), Thanksgiving recess; nitrogen in urine Nov. 30–Dec. 1, 7.63 gms.
[2] Computed; see table 33, p. 269.

TABLE 54.—*Nitrogen balance and energy available to body*—ALLEN S. PEABODY—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Dec. 3– 4	6.26	(1.44)	5.91	−1.09	1,262	(211)	47	1,004
Dec. 4– 5	14.32	(1.44)	12.92	− .04	2,609	(211)	103	2,295
Dec. 5– 6	11.75	(1.44)	....	....	2,343	(211)	(95)	2,037
Dec. 6– 7	12.55	(1.44)	10.91	+ .20	2,604	(211)	87	2,306
Dec. 7– 8	9.90	(1.44)	11.35	−2.89	2,213	(211)	91	1,911
Dec. 8– 9	11.28	(1.44)	9.29	+ .55	2,339	(211)	74	2,054
Dec. 9–10	[2]21.25	....	....	....	[2]5,666	(211)	(82)	5,373
Dec. 10–11	11.75	1.70	11.21	−1.16	2,641	259	90	2,292
Dec. 11–12	14.14	1.70	10.82	+1.62	2,863	259	87	2,517
Dec. 12–13	15.01	1.70	11.88	+1.43	3,113	259	95	2,759
Dec. 13–14	13.10	1.70	12.19	− .79	2,793	259	98	2,436
Dec. 14–15	12.22	1.70	12.22	−1 70	2,945	259	98	2,588
Dec. 15–16	13.80	(1.70)	10.98	+1.12	3,374	(259)	88	3,027
Dec. 16–17	13.40	(1.70)	....	....	2,939	(259)	(93)	2,587
Dec. 17–18	16.01	(1.70)	12.28	+2.03	3,150	(259)	98	2,793
Dec. 18–19	15.11	(1.70)	13.82	− .41	3,171	(259)	111	2,801
Dec. 19–20[1]	12.83	(1.70)	13.24	−2.11	2,915	(259)	106	2,550
Av. Dec. 3–20	13.22	....	11.36	....	....	....	....	2,549
1918.								
Jan. 7– 8	7.82	(1.24)	10.24	−3.66	1,319	(172)	82	1,065
Jan. 8– 9	8.85	(1.24)	10.25	−2.64	1,499	(172)	82	1,245
Jan. 9–10	7.83	(1.24)	10.70	−4.11	1,335	(172)	86	1,077
Jan. 10–11	7.22	(1.24)	11.11	−5.13	1,349	(172)	89	1,088
Jan. 11–12	7.21	(1.24)	10.91	−4.94	1,125	(172)	87	866
Jan. 12–13	8.46	(1.24)	11.76	−4.54	1,796	(172)	94	1,530
Jan. 13–14	[2]21.20	(1.24)	12.67	+7.29	[2]5,221	(172)	101	4,948
Jan. 14–15	6.08	1.24	8.43	−3.59	1,240	172	67	1,001
Jan. 15–16	5.46	1.24	6.51	−2.29	1,016	172	52	792
Jan. 16–17	10.47	1.24	9.87	− .64	1,949	172	79	1,698
Jan. 17–18	6.27	1.24	9.17	−4.14	993	172	73	748
Jan. 18–19	11.32	1.24	9.25	+ .83	1,955	172	74	1,709
Jan. 19–20	10.45	1.24	9.87	− .66	2,132	172	79	1,881
Jan. 20–21	8.45	1.24	9.51	−2.30	1,801	172	76	1,553
Jan. 21–22	8.28	1.24	9.07	−2.03	1,459	172	73	1,214
Jan. 22–23	10.12	1.24	11.15	−2.27	1,687	172	89	1,426
Jan. 23–24	7.74	1.24	9.65	−3.15	1,638	172	77	1,389
Jan. 24–25	12.66	1.24	10.10	+1.32	2,161	172	81	1,908
Av. Jan. 7–25	9.22	....	10.01	....	....	....	....	1,508
Jan. 25–26	10.97	1.24	10.94	−1.21	2,394	172	88	2,134
Jan. 26–27	11.00	1.24	10.91	−1.15	2,320	172	87	2,061
Jan. 27–28	9.11	1.24	12.48	−4.61	1,757	172	100	1,485
Jan. 28–29	12.44	1.24	9.89	+1.31	2,302	172	79	2,051
Jan. 29–30	17.53	1.24	15.76	+ .53	3,115	172	126	2,817
Jan. 30–31	12.27	(1.24)	10.83	+ .20	2,777	(172)	87	2,518
Jan. 31–Feb. 1	19.83	(1.24)	13.12	+5.47	3,349	(172)	105	3,072
Feb. 1– 2	16.56	(1.24)	12.90	+2.42	3,033	(172)	103	2,758
Feb. 2– 3	10.68	(1.24)	11.59	−2.15	2,227	(172)	93	1,962
Av. Jan. 25–Feb. 3	13.38	....	12.05	....	....	....	....	2,318

[1] Dec. 20, 1917–Jan. 6, 1918 (inclusive), Christmas recess. [1] Computed; see table 33, p. 269.

TABLE 55.—*Nitrogen balance and energy available to body*—R. WALLACE PECKHAM.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	......	......	......	......	......	......	......	......
Sept. 28–29	......	......	15.62	......	......	......	......	......
Sept. 29–30	......	......	13.41	......	......	......	......	......
Sept. 30–Oct. 1	......	......	......	......	......	......	......	......
Oct. 1– 2	16.51	(1.37)	12.89	+2.25	3,605	(191)	103	3,311
Oct. 2– 3	14.93	(1.37)	14.64	−1.08	2,974	(191)	117	2,666
Oct. 3– 4	15.54	(1.37)	11.54	+2.63	3,656	(191)	92	3,373
Av. Oct. 1–4	15.66	......	13.02	......	......	......	......	3,117
Reduced diet:								
Oct. 4– 5	10.46	(1.37)	13.44	−4.35	2,312	(191)	108	2,013
Oct. 5– 6	11.85	(1.37)	13.44	−2.96	2,127	(191)	108	1,828
Oct. 6– 7	10.87	(1.37)	11.80	−2.30	2,553	(191)	94	2,268
Oct. 7– 8	9.65	(1.37)	15.13	−6.85	2,119	(191)	121	1,807
Oct. 8– 9	13.98	1.37	12.15	+ .46	2,415	191	97	2,127
Oct. 9–10	12.21	1.37	13.94	−3.10	2,207	191	112	1,904
Oct. 10–11	13.13	1.37	15.18	−3.42	2,519	191	121	2,207
Oct. 11–12	10.65	1.37	10.22	− .94	2,301	191	82	2,028
Oct. 12–13	12.39	(1.15)	11.95	− .71	2,721	(183)	96	2,442
Oct. 13–14	9.36	(1.15)	11.60	−3.39	2,279	(183)	93	2,003
Oct. 14–15	[1]18.83	......	......	......	[1]3,016	(183)	(101)	2,732
Av. Oct. 4–15	12.13	......	12.89	......	......	......	......	2,124
Oct. 15–16	11.04	(1.15)	13.46	−3.57	1,981	(183)	108	1,690
Oct. 16–17	13.05	(1.15)	12.18	− .28	2,166	(183)	97	1,886
Oct. 17–18	10.14	.92	12.98	−3.76	1,850	175	104	1,571
Oct. 18–19	14.75	.92	14.56	− .73	2,580	175	116	2,289
Oct. 19–20	10.93	.92	11.58	−1.57	1,894	175	93	1,626
Oct. 20–21	11.34	.92	13.42	−3.00	2,133	175	107	1,851
Oct. 21–22	9.71	(.94)	13.00	−4.23	2,369	(159)	104	2,106
Oct. 22–23	8.87	(.94)	12.19	−4.26	1,613	(159)	98	1,356
Oct. 23–24	10.68	(.94)	10.95	−1.21	2,109	(159)	88	1,862
Oct. 24–25	13.58	(.94)	9.06	+3.58	2,500	(159)	72	2,269
Oct. 25–26	8.46	(.94)	9.51	−1.99	1,500	(159)	76	1,265
Oct. 26–27	11.87	(.94)	12.69	−1.76	2,244	(159)	102	1,983
Oct. 27–28	8.71	(.94)	12.31	−4.54	1,811	(159)	98	1,554
Oct. 28–29	[2]18.83	......	......	......	[2]3,016	(159)	(102)	2,755
Av. Oct. 15–29	11.57	......	12.15	......	......	......	......	1,862
Oct. 29–30	11.73	(.94)	13.18	−2.39	1,980	(159)	105	1,716
Oct. 30–31	12.37	(.94)	12.22	− .79	1,774	(159)	98	1,517
Oct. 31–Nov. 1	8.65	.96	10.70	−3.01	1,577	143	86	1,348
Nov. 1– 2	9.52	.96	12.64	−4.08	1,531	143	101	1,287
Nov. 2– 3	9.76	.96	13.15	−4.35	1,718	143	105	1,470
Nov. 3– 4	8.33	.96	13.33	−5.96	1,667	143	107	1,417
Nov. 4– 5	8.61	.96	12.66	−5.01	1,758	143	101	1,514
Nov. 5– 6	8.55	.96	10.28	−2.69	1,358	143	82	1,133
Nov. 6– 7	8.15	.96	10.64	−3.45	1,547	143	85	1,319
Nov. 7– 8	9.50	.96	10.44	−1.90	1,935	143	84	1,708
Nov. 8– 9	6.57	.96	11.81	−6.20	1,340	143	94	1,103
Nov. 9–10	7.66	.96	4.26	+2.44	1,348	143	34	1,171

[1] Assumed. [2] Computed; see table 33, p. 269.

TABLE 55.—*Nitrogen balance and energy available to body*—R. WALLACE PECKHAM—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 10–11..........	9.17	.96	14.80	−6.59	1,635	143	118	1,374
Nov. 11–12..........	[2]11.69	.96	....	....	[2]2,650	143	(104)	2,403
Nov. 12–13..........	8.37	.96	11.07	−3.66	1,784	143	89	1,552
Nov. 13–14..........	11.66	.96	12.07	−1.37	1,909	143	97	1,669
Nov. 14–15..........	10.83	.96	12.72	−2.85	1,676	143	102	1,431
Nov. 15–16..........	8.09	.96	11.78	−4.65	1,511	143	94	1,274
Nov. 16–17..........	10.07	.96	11.31	−2.20	1,382	143	90	1,149
Nov. 17–18..........	8.32	.96	10.08	−2.72	1,566	143	81	1,342
Nov. 18–19..........	7.88	.96	11.72	−4.80	1,445	143	94	1,208
Nov. 19–20..........	10.44	.96	11.84	−2.36	1,990	143	95	1,752
Nov. 20–21..........	10.85	.96	9.60	+ .29	1,771	143	77	1,551
Nov. 21–22..........	6.28	.96	17.90	−12.58	1,339	143	143	1,053
Nov. 22–23..........	8.70	.96	10.43	−2.69	1,911	143	83	1,685
Nov. 23–24..........	8.94	.96	9.90	−1.92	1,844	143	79	1,622
Nov. 24–25..........	9.01	.96	7.93	+ .12	1,664	143	63	1,458
Nov. 25–26..........	[2]17.44	.96	....	....	[2]3,541	143	(81)	3,317
Nov. 26–27..........	9.10	.96	....	....	1,646	143	(81)	1,422
Nov. 27–28..........	9.56	.96	12.22	−3.62	1,688	143	98	1,447
Nov. 28–29..........	6.64	.96	16.28	−10.60	1,568	143	130	1,295
Av. Oct. 29–Nov. 29.	9.43	....	11.68	....	....	....	....	1,507
Nov. 29–30..........	....	1.44	14.87	....	....	220	....	....
Nov. 30–Dec. 1......	....	1.44	15.83	....	....	220	....	....
Dec. 1– 2..........	....	1.44	11.39	....	....	220	....	....
Dec. 2– 3..........	....	1.44	12.23	....	....	220	....	....
Dec. 3– 4..........	8.70	1.44	7.27	− .01	1,685	220	58	1,407
Dec. 4– 5..........	12.81	1.44	12.95	−1.58	2,236	220	104	1,912
Dec. 5– 6..........	9.75	1.44	12.40	−4.09	1,927	220	99	1,608
Dec. 6– 7..........	10.41	1.44	11.55	−2.58	2,112	220	92	1,800
Dec. 7– 8..........	8.45	1.44	11.35	−4.34	1,840	220	91	1,529
Dec. 8– 9..........	8.64	1.44	10.17	−2.97	1,745	220	81	1,444
Av. Dec. 3–9......	9.79	....	10.95	....	....	....	....	1,617
Dec. 9–10..........	[2]20.15	1.44	....	....	[2]4,414	220	(94)	4,100
Dec. 10–11..........	9.63	1.08	13.28	−4.73	2,261	179	106	1,976
Dec. 11–12..........	10.75	1.08	9.67	±0.00	2,119	179	77	1,863
Dec. 12–13..........	12.02	1.08	10.90	+ .04	2,329	179	87	2,063
Dec. 13–14..........	10.34	1.08	11.51	−2.25	2,085	179	92	1,814
Dec. 14–15..........	8.48	1.08	10.21	−2.81	2,150	179	82	1,889
Dec. 15–16..........	10.51	(1.08)	....	....	2,652	(179)	(84)	2,389
Dec. 16–17..........	9.55	(1.08)	....	....	2,091	(179)	(84)	1,828
Dec. 17–18..........	12.76	(1.08)	10.76	+ .92	2,392	(179)	86	2,127
Dec. 18–19..........	11.71	(1.08)	11.67	−1.04	2,345	(179)	93	2,073
Dec. 19–20[1].........	10.43	(1.08)	11.81	−2.46	2,306	(179)	94	2,033
Av. Dec. 9–20.....	11.48	....	11.23	....	....	....	....	2,196
1918.								
Jan. 5– 6..........	00.00	(.96)	11.89	−12.85	0,000	(134)	95	−229
Jan. 6– 7..........	00.00	(.96)	9.62	−10.58	0,000	(134)	77	−211
Jan. 7– 8..........	13.08	(.96)	12.58	− .46	2,255	(134)	101	2,020
Jan. 8– 9..........	13.49	(.96)	13.36	− .83	2,447	(134)	107	2,206
Jan. 9–10..........	7.19	(.96)	7.85	−1.62	1,219	(134)	63	1,022

[1] Dec. 20, 1917–Jan. 6, 1918 (inclusive), Christmas recess. [2] Computed; see table 33, p. 269.

TABLE 55.—*Nitrogen balance and energy available to body*—R. WALLACE PECKHAM—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Jan. 10–11	8.97	(.96)	11.29	−3.28	1,658	(134)	90	1,434
Jan. 11–12	8.84	(.96)	11.97	−4.09	1,367	(134)	96	1,137
Jan. 12–13	10.76	(.96)	12.45	−2.65	2,131	(134)	100	1,897
Jan. 13–14	[1]11.30	(.96)	13.26	−2.92	[1]2,900	(134)	106	2,660
Jan. 14–15	8.10	.96	11.30	−4.16	1,464	134	90	1,240
Jan. 15–16	6.82	.96	8.18	−2.32	1,221	134	65	1,022
Jan. 16–17	11.51	.96	8.33	+2.22	2,027	134	67	1,826
Jan. 17–18	6.27	.96	9.92	−4.61	969	134	79	756
Jan. 18–19	11.00	.96	11.56	−1.52	1,898	134	92	1,672
Jan. 19–20	4.22	.96	12.02	−8.76	1,235	134	96	1,005
Av. Jan. 5–20	8.10	....	11.04	....	....	....	....	1,326
Jan. 20–21	8.94	.96	8.11	− .13	1,886	134	65	1,687
Jan. 21–22	8.28	.96	8.59	−1.27	1,435	134	69	1,232
Jan. 22–23	9.41	.96	9.56	−1.11	1,340	134	76	1,130
Jan. 23–24	7.85	.96	9.54	−2.65	1,647	134	76	1,437
Jan. 24–25	9.21	.96	9.51	−1.26	1,855	134	76	1,645
Jan. 25–26	8.03	.96	9.67	−2.60	1,647	134	77	1,436
Jan. 26–27	9.21	.96	10.40	−2.15	1,992	134	83	1,775
Jan. 27–28	9.11	.96	11.95	−3.80	1,733	134	96	1,503
Jan. 28–29	8.49	.96	9.19	−1.66	1,524	134	74	1,316
Jan. 29–30	11.25	.96	9.20	+1.09	2,062	134	74	1,854
Jan. 30–31	9.68	(.96)	9.68	− .96	2,092	(134)	77	1,881
Jan. 31–Feb. 1	12.55	(.96)	11.40	+ .19	2,098	(134)	91	1,873
Feb. 1–2	13.48	(.96)	9.85	+2.67	2,507	(134)	79	2,294
Feb. 2–3	8.52	(.96)	10.32	−2.76	1,814	(134)	83	1,597
Av. Jan. 20–Feb. 3	9.57	....	9.78	....	....	....	....	1,619

[1] Computed; see table 33, p. 269.

TABLE 55a.—*Nitrogen in urine during Christmas recess*—R. WALLACE PECKHAM.

Date.	Nitrogen in urine per 24 hours.	Date.	Nitrogen in urine per 24 hours.
1917.	*gm.*	1918.	*gm.*
Dec. 20–21	14.07	Jan. 1–2	15.70
Dec. 21–22	10.81	Jan. 2–3	17.59
Dec. 22–29[1]	....	Jan. 3–4	13.73
Dec. 30–31	7.96	Jan. 4–5	9.55

[1] Inclusive; no record.

TABLE 56.—*Nitrogen balance and energy available to body*—WESLEY G. SPENCER.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	....	....	14.63	....	....	....	....	....
Sept. 28–29	....	....	14.81	....	....	....	....	....
Sept. 29–30	....	....	14.56	....	....	....	....	....
Sept. 30–Oct. 1	....	....	....	....	....	....	....	....
Oct. 1– 2	17.79	1.52	13.85	+2.42	3,706	122	111	3,473
Oct. 2– 3	14.93	1.52	14.70	−1.29	2,974	122	118	2,734
Oct. 3– 4	15.54	1.52	14.49	− .47	3,656	122	116	3,418
Av. Oct. 1–4	16.09	....	14.35	....	....	....	....	3,208
Reduced diet:								
Oct. 4– 5	10.46	(1.43)	11.92	−2.89	2,304	(134)	95	2,075
Oct. 5– 6	11.85	(1.43)	13.69	−3.27	2,119	(134)	110	1,875
Oct. 6– 7	10.87	(1.43)	12.47	−3.03	2,545	(134)	100	2,311
Oct. 7– 8	9.65	(1.43)	10.38	−2.16	2,111	(134)	83	1,894
Oct. 8– 9	13.82	1.33	12.93	− .44	2,379	146	103	2,130
Oct. 9–10	12.21	1.33	12.88	−2.00	2,199	146	103	1,950
Oct. 10–11	12.19	1.33	12.99	−2.13	2,337	146	104	2,087
Oct. 11–12	11.11	1.33	11.69	−1.91	2,380	146	94	2,140
Oct. 12–13	12.39	(1.09)	11.35	− .05	2,713	(129)	91	2,493
Oct. 13–14	9.59	(1.09)	12.24	−3.74	2,289	(129)	98	2,062
Oct. 14–15	[1]14.73	....	....	....	[1]3,248	(129)	(97)	3,022
Av. Oct. 4–15	11.72	....	12.25	....	....	....	....	2,185
Oct. 15–16	11.13	(1.09)	11.92	−1.88	1,998	(129)	95	1,774
Oct. 16–17	13.05	(1.09)	12.69	− .73	2,174	(129)	102	1,943
Oct. 17–18	10.36	.84	12.37	−2.85	1,859	112	99	1,648
Oct. 18–19	14.59	.84	12.93	+ .82	2,567	112	103	2,352
Oct. 19–20	9.84	.84	11.76	−2.76	1,708	112	94	1,502
Oct. 20–21	9.78	.84	11.80	−2.86	1,876	112	94	1,670
Oct. 21–22	9.40	(.97)	11.94	−3.51	2,327	(125)	96	2,106
Oct. 22–23	8.87	(.97)	10.55	−2.65	1,621	(125)	84	1,412
Oct. 23–24	10.37	(.97)	11.25	−1.85	2,067	(125)	90	1,852
Oct. 24–25	13.11	(.97)	11.75	+ .39	2,430	(125)	94	2,211
Oct. 25–26	8.15	(.97)	9.81	−2.63	1,458	(125)	78	1,255
Oct. 26–27	10.62	(.97)	12.21	−2.56	2,021	(125)	98	1,798
Oct. 27–28	8.40	(.97)	11.75	−4.32	1,761	(125)	94	1,542
Oct. 28–29	[2]14.73	....	....	....	[2]3,248	(125)	(94)	3,029
Av. Oct. 15–29	10.89	....	11.75	....	....	....	....	1,864
Oct. 29–30	12.19	(.97)	11.63	− .41	2,082	(125)	93	1,864
Oct. 30–31	12.18	(.97)	13.07	−1.86	1,826	(125)	105	1,596
Oct. 31–Nov. 1	9.60	1.10	11.12	−2.62	1,882	138	89	1,655
Nov. 1– 2	9.52	1.10	12.25	−3.83	1,578	138	98	1,342
Nov. 2– 3	10.55	1.10	12.09	−2.64	2,056	138	97	1,821
Nov. 3– 4	8.33	1.10	....	....	1,762	138	(94)	1,530
Nov. 4– 5	8.61	(1.25)	11.31	−3.95	1,845	(153)	90	1,602
Nov. 5– 6	9.59	(1.25)	13.05	−4.71	1,555	(153)	104	1,298
Nov. 6– 7	9.95	(1.25)	11.35	−2.65	1,912	(153)	91	1,668
Nov. 7– 8	11.02	(1.25)	11.55	−1.78	2,199	(153)	92	1,954
Nov. 8– 9	8.10	(1.25)	9.88	−3.03	1,559	(153)	79	1,327
Nov. 9–10	7.97	(1.25)	10.95	−4.23	1,390	(153)	88	1,149
Nov. 10–11	9.17	(1.25)	13.15	−5.23	1,635	(153)	105	1,377
Nov. 11–12	[2]8.93	....	....	....	[2]3,241	(153)	(90)	2,998
Av. Oct. 29–Nov. 12	9.69	....	11.78	....	....	....	....	1,656

[1] Assumed. [2] Computed; see table 33, p. 269.

TABLE 56.—*Nitrogen balance and energy available to body*—WESLEY G. SPENCER—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 12–13	8.37	1.39	9.24	−2.26	1,784	168	74	1,542
Nov. 13–14	11.66	1.39	10.54	− .27	1,949	168	84	1,697
Nov. 14–15	10.83	1.39	12.85	−3.41	1,676	168	103	1,405
Nov. 15–16	8.09	1.39	12.12	−5.42	1,625	168	97	1,360
Nov. 16–17	11.06	1.39	13.08	−3.41	1,891	168	105	1,618
Av. Nov. 12–17	10.00	....	11.57	....	....	....	....	1,524
Nov. 17–18	6.52	1.39	8.61	−3.48	2,701	168	69	2,464
Nov. 18–19	10.55	(1.39)	11.15	−1.99	2,365	(168)	89	2,108
Nov. 19–20	13.79	(1.39)	11.55	+ .85	2,892	(168)	92	2,632
Nov. 20–21	12.39	(1.39)	11.82	− .82	2,281	(168)	95	2,018
Nov. 21–22	12.30	(1.39)	11.14	− .23	2,819	(168)	89	2,562
Nov. 22–23	14.53	(1.39)	10.54	+2.60	2,946	(168)	84	2,694
Nov. 23–24	12.49	(1.39)	12.11	−1.01	2,695	(168)	97	2,430
Nov. 24–25	11.09	(1.39)	11.73	−2.03	2,167	(168)	94	1,905
Nov. 25–26	[2]12.82	....	....	....	[2]3,369	(168)	(84)	3,117
Nov. 26–27	14.17	(1.39)	9.07	+3.71	2,891	(168)	73	2,650
Nov. 27–28	9.71	(1.39)	12.32	−4.00	1,765	(168)	99	1,498
Nov. 28–29	7.89	(1.39)	10.94	−4.44	1,800	(168)	88	1,544
Nov. 29–30[3]	....	....	13.86	....	....	....	....	....
Av. Nov. 17–29	11.52	....	11.00	....	....	....	....	2,302
Dec. 3– 4	8.70	(1.39)	11.20	−3.89	1,645	(168)	90	1,387
Dec. 4– 5	11.74	(1.39)	11.73	−1.38	2,024	(168)	94	1,762
Dec. 5– 6	12.22	(1.39)	14.81	−3.98	2,366	(168)	118	2,080
Dec. 6– 7	12.08	(1.39)	11.95	−1.26	2,457	(168)	96	2,193
Dec. 7– 8	7.84	(1.39)	10.83	−4.38	1,763	(168)	87	1,508
Dec. 8– 9	9.32	(1.39)	11.66	−3.73	1,920	(168)	93	1,659
Dec. 9–10	[1]12.82	....	....	....	[1]3,369	(168)	(82)	3,119
Dec. 10–11	9.67	(1.39)	8.79	− .51	2,295	(168)	70	2,057
Dec. 11–12	17.35	(1.39)	13.11	+2.85	3,518	(168)	105	3,245
Dec. 12–13	14.39	(1.39)	9.40	+3.60	2,966	(168)	75	2,723
Av. Dec. 3–13	11.61	....	11.50	....	....	....	....	2,173
Dec. 13–14	7.79	(1.39)	12.31	−5.91	1,939	(168)	98	1,673

[1] Assumed.
[2] Computed; see table 33, p. 269.
[3] Nov. 30–Dec. 2 (inclusive), Thanksgiving recess.

TABLE 57.—*Nitrogen balance and energy available to body*—LESLIE J. TOMPKINS.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	......	......	8.35	......	......	......	......	......
Sept. 28–29	......	......	5.30	......	......	......	......	......
Sept. 29–30	......	......	5.87	......	......	......	......	......
Sept. 30–Oct. 1	......	......	......	......	......	......	......	......
Oct. 1–2	14.63	1.32	8.78	+4.53	3,300	127	70	3,103
Oct. 2–3	14.93	1.32	9.98	+3.63	2,974	127	80	2,767
Oct. 3–4	15.17	1.32	10.22	+3.63	3,584	127	82	3,375
Av. Oct. 1–4	14.91	......	9.66	......	......	......	......	3,082
Reduced diet:								
Oct. 4–5	10.46	(1.27)	9.24	− .05	2,304	(139)	74	2,091
Oct. 5–6	11.85	(1.27)	9.57	+1.01	2,119	(139)	77	1,903
Oct. 6–7	10.87	(1.27)	9.90	− .30	2,545	(139)	79	2,327
Oct. 7–8	8.89	(1.27)	9.14	−1.52	2,047	(139)	73	1,835
Oct. 8–9	13.82	1.21	9.25	+3.36	2,379	151	74	2,154
Oct. 9–10	12.05	1.21	10.73	+ .11	2,170	151	86	1,933
Oct. 10–11	12.35	1.21	11.04	+ .10	2,366	151	88	2,127
Oct. 11–12	11.11	1.21	8.74	+1.16	2,380	151	70	2,159
Oct. 12–13	11.45	(1.13)	10.16	+ .16	2,425	(140)	81	2,204
Av. Oct. 4–13	11.43	......	9.75	......	......	......	......	2,081
Oct. 13–14	8.60	(1.13)	7.74	− .27	2,008	(140)	62	1,806
Oct. 14–15	[1]13.52	......	......	......	[1]2,525	(140)	(71)	2,314
Oct. 15–16	11.15	(1.13)	9.96	+ .06	1,986	(140)	80	1,766
Oct. 16–17	12.45	(1.13)	10.19	+1.13	2,037	(140)	82	1,815
Oct. 17–18	9.83	1.05	9.58	− .80	1,776	129	77	1,570
Oct. 18–19	14.75	1.05	11.71	+1.99	2,596	129	94	2,373
Oct. 19–20	9.53	1.05	10.70	−2.22	1,650	129	86	1,435
Oct. 20–21	9.94	1.05	9.65	− .76	1,873	129	77	1,667
Oct. 21–22	9.09	(.92)	8.14	+ .03	2,253	(122)	65	2,066
Oct. 22–23	8.87	(.92)	8.05	− .10	1,669	(122)	64	1,483
Oct. 23–24	10.06	(.92)	10.35	−1.21	2,009	(122)	83	1,804
Oct. 24–25	12.48	(.92)	10.39	+1.17	2,314	(122)	83	2,109
Oct. 25–26	7.37	(.92)	8.89	−2.44	1,353	(122)	71	1,160
Oct. 26–27	10.47	(.92)	8.65	+ .90	2,000	(122)	69	1,809
Oct. 27–28	8.40	(.92)	9.36	−1.88	1,761	(122)	75	1,564
Oct. 28–29	[2]13.52	......	......	......	[2]2,525	(122)	(73)	2,330
Oct. 29–30	11.41	(.92)	8.86	+1.63	1,930	(122)	71	1,737
Av. Oct. 13–30	10.67	......	9.48	......	......	......	......	1,812
Oct. 30–31	11.12	(.92)	9.48	+ .72	1,543	(122)	76	1,345
Oct. 31–Nov. 1	8.50	.79	10.47	−2.76	1,548	114	84	1,350
Nov. 1–2	9.20	.79	10.42	−2.01	1,536	114	83	1,339
Nov. 2–3	9.29	.79	10.63	−2.13	1,647	114	85	1,448
Nov. 3–4	8.33	.79	10.53	−2.99	1,683	114	84	1,485
Nov. 4–5	8.30	(.92)	8.76	−1.38	1,756	(124)	70	1,562
Nov. 5–6	8.24	(.92)	8.31	− .99	1,316	(124)	66	1,126
Nov. 6–7	7.53	(.92)	8.78	−2.17	1,439	(124)	70	1,245
Nov. 7–8	8.79	(.92)	9.29	−1.42	1,796	(124)	74	1,598
Nov. 8–9	6.26	(.92)	9.51	−4.17	1,298	(124)	76	1,098

[1] Assumed. [2] Computed; see table 33, p. 269.

TABLE 57.—*Nitrogen balance and energy available to body*—LESLIE J. TOMPKINS—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N ×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 9–10..........	7.50	(.92)	7.59	−1.01	1,319	(124)	61	1,134
Nov. 10–11..........	8.70	(.92)	9.81	−2.03	1,564	(124)	78	1,362
Nov. 11–12..........	[1]15.19	....	....	....	[1]2,925	(124)	(68)	2,733
Nov. 12–13..........	7.60	1.04	7.11	− .55	1,612	133	57	1,422
Nov. 13–14..........	9.57	1.04	6.45	+2.08	1,459	133	52	1,274
Nov. 14–15..........	10.83	1.04	9.74	+ .05	1,692	133	78	1,481
Nov. 15–16..........	7.85	1.04	9.40	−2.59	1,485	133	75	1,277
Nov. 16–17..........	8.88	1.04	10.46	−2.62	1,153	133	84	936
Nov. 17–18..........	8.50	1.04	10.37	−2.91	1,674	133	83	1,458
Nov. 18–19..........	7.57	(.98)	9.74	−3.15	1,535	(124)	78	1,333
Av.Oct.30–Nov.19..	8.89	....	9.31	....	....	....	....	1,400
Nov. 19–20..........	9.97	(.98)	9.44	− .45	1,919	(124)	76	1,719
Nov. 20–21..........	9.76	(.98)	9.02	− .24	1,669	(124)	72	1,473
Nov. 21–22..........	6.01	(.98)	....	....	1,382	(124)	(64)	1,194
Nov. 22–23..........	7.57	(.98)	6.84	− .25	1,719	(124)	55	1,540
Nov. 23–24..........	7.85	(.98)	7.32	− .45	1,657	(124)	59	1,474
Nov. 24–25..........	8.54	(.98)	6.64	+ .92	1,617	(124)	53	1,440
Nov. 25–26..........	[1]15.64	....	....	....	[1]3,597	(124)	(43)	3,430
Nov. 26–27..........	9.67	(.98)	4.11	+4.58	1,786	(124)	33	1,629
Nov. 27–28[2]..........	7.41	(.98)	7.84	−1.41	1,629	(124)	63	1,442
Av. Nov. 19–28...	9.16	....	7.32	....	....	....	....	1,705
Dec. 3– 4..........	5.01	(.98)	....	....	1,318	(124)	(35)	1,159
Dec. 4– 5..........	10.18	(.98)	4.43	+4.77	1,750	(124)	35	1,591
Dec. 5– 6..........	8.19	(.98)	6.92	+ .29	1,634	(124)	55	1,455
Dec. 6– 7..........	8.54	(.98)	8.71	−1.15	1,762	(124)	70	1,568
Dec. 7– 8..........	5.23	(.98)	6.47	−2.22	1,092	(124)	52	916
Dec. 8– 9..........	7.86	(.98)	7.54	− .66	1,644	(124)	60	1,460
Dec. 9–10..........	[1]13.62	....	....	....	[1]3,347	(124)	(66)	3,157
Dec. 10–11..........	5.16	.92	8.93	−4.69	1,281	115	71	1,095
Dec. 11–12..........	6.52	.92	6.41	− .81	1,305	115	51	1,139
Dec. 12–13..........	7.44	.92	7.78	−1.26	1,463	115	62	1,286
Dec. 13–14..........	9.40	.92	9.53	−1.05	1,935	115	76	1,744
Av. Dec. 3–14.....	7.92	....	7.41	....	....	....	....	1,506
Dec. 14–15..........	8.17	.92	8.17	− .92	2,076	115	65	1,896
Dec. 15–16..........	10.03	(.92)	....	....	2,563	(115)	(74)	2,374
Dec. 16–17..........	8.13	(.92)	....	....	1,833	(115)	(74)	1,644
Dec. 17–18..........	11.73	(.92)	10.20	+ .61	2,165	(115)	82	1,968
Dec. 18–19..........	10.87	(.92)	6.27	+3.68	2,148	(115)	50	1,983
Dec. 19–20[3]..........	9.61	(.92)	7.80	+ .89	2,032	(115)	62	1,855
Av. Dec. 14–20....	9.76	....	8.11	....	....	....	....	1,953
1918.								
Jan. 12–13..........	6.10	(.87)	5.82	− .59	1,257	(94)	47	1,116
Jan. 13–14..........	[1]16.12	(.87)	7.58	+7.67	[1]3,024	(94)	61	2,869
Jan. 14–15..........	7.62	.87	7.53	− .78	1,414	94	60	1,260
Jan. 15–16..........	6.34	.87	6.45	− .98	1,171	94	52	1,025
Jan. 16–17..........	6.89	.87	6.94	− .92	1,297	94	56	1,147

[1] Computed; see table 33, p. 269.
[2] Nov. 28–Dec. 2 (inclusive), Thanksgiving recess.
[3] Dec. 20, 1917–Jan. 11, 1918 (inclusive), Christmas recess.

TABLE 57.—*Nitrogen balance and energy available to body*—LESLIE J. TOMPKINS—continued.

Date.	Nitrogen per 24 hours in— Food.	Feces.	Urine.	Nitrogen balance.	Energy per 24 hours of— Food.	Feces.	Urine (N×8.0).	Net energy.
1918—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Jan. 17–18	5.36	.87	7.98	−3.49	912	94	64	754
Jan. 18–19	5.61	.87	9.68	−4.94	1,008	94	77	837
Jan. 19–20	5.96	.87	6.89	−1.80	1,250	94	55	1,101
Jan. 20–21	7.04	.87	8.07	−1.90	1,404	94	65	1,245
Jan. 21–22	6.84	.87	7.68	−1.71	1,188	94	61	1,033
Jan. 22–23	9.80	.87	7.78	+1.15	1,638	94	62	1,482
Jan. 23–24	7.05	.87	7.80	−1.62	1,547	94	62	1,391
Jan. 24–25	8.08	.87	6.99	+ .22	1,650	94	56	1,500
Av. Jan. 12–25	7.60	....	7.48	....	....	....	....	1,289
Jan. 25–26	6.86	.87	5.59	+ .40	1,798	94	45	1,659
Jan. 26–27	8.30	.87	6.92	+ .51	1,850	94	55	1,701
Jan. 27–28	7.76	.87	8.51	−1.62	1,516	94	68	1,354
Jan. 28–29	7.95	.87	6.66	+ .42	1,429	94	53	1,282
Jan. 29–30	10.45	.87	7.25	+2.33	1,957	94	58	1,805
Jan. 30–31	9.12	(.87)	8.92	− .67	2,033	(94)	71	1,868
Jan. 31–Feb. 1	11.75	(.87)	8.59	+2.29	1,973	(94)	69	1,810
Feb. 1– 2	10.09	(.87)	10.37	−1.15	1,940	(94)	83	1,763
Feb. 2– 3	7.11	(.87)	6.54	− .30	1,866	(94)	52	1,720
Av. Jan. 25–Feb. 3	8.82	....	7.71	....	....	....	....	1,662

TABLE 58.—*Nitrogen balance and energy available to body*—RONALD T. VEAL.

Date.	Nitrogen per 24 hours in— Food.	Feces.	Urine.	Nitrogen balance.	Energy per 24 hours of— Food.	Feces.	Urine (N×8.0).	Net energy.
1917.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Normal diet:								
Sept. 27–28	....	....	16.33	....	....	....	....	....
Sept. 28–29	....	....	17.21	....	....	....	....	....
Sept. 29–30	....	....	12.70	....	....	....	....	....
Sept. 30–Oct. 1	....	....	....	....	....	....	....	....
Oct. 1– 2	16.25	1.19	15.24	− .18	3,525	120	122	3,283
Oct. 2– 3	14.93	1.19	13.41	+ .33	2,974	120	107	2,747
Oct. 3– 4	15.54	1.19	13.00	+1.35	2,656	120	104	2,432
Av. Oct. 1–4	15.57	....	13.88	....	....	....	....	2,821
Reduced diet:								
Oct. 4– 5	10.46	(1.11)	12.82	−3.47	2,304	(122)	103	2,079
Oct. 5– 6	11.85	(1.11)	10.38	+ .36	2,119	(122)	83	1,914
Oct. 6– 7	10.87	(1.11)	10.82	−1.06	2,545	(122)	87	2,336
Oct. 7– 8	9.14	(1.11)	11.31	−3.28	2,062	(122)	90	1,850
Oct. 8– 9	13.67	1.02	11.18	+1.47	2,350	124	89	2,137
Oct. 9–10	12.05	1.02	12.21	−1.18	2,170	124	98	1,948
Oct. 10–11	11.52	1.02	11.51	−1.01	2,213	124	92	1,997
Oct. 11–12	10.80	1.02	10.57	− .79	2,322	124	85	2,113
Oct. 12–13	12.01	(.92)	11.30	− .21	2,642	(114)	90	2,438
Oct. 13–14	9.36	(.92)	10.30	−1.86	2,239	(114)	82	2,043
Oct. 14–15	[1]16.01	....	....	....	[1]4,057	(114)	(84)	3,859
Av. Oct. 4–15	11.61	....	11.24	....	....	....	....	2,247

[1] Assumed.

TABLE 58.—*Nitrogen balance and energy available to body*—RONALD T. VEAL—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Oct. 15–16	10.73	(.92)	10.58	− .77	1,907	(114)	85	1,708
Oct. 16–17	12.29	(.92)	10.93	+ .44	2,008	(114)	87	1,807
Oct. 17–18	9.60	.82	11.34	−2.56	1,750	104	91	1,555
Oct. 18–19	14.30	.82	12.61	+ .87	2,513	104	101	2,308
Oct. 19–20	9.68	.82	11.01	−2.15	1,679	104	88	1,487
Oct. 20–21	9.78	.82	12.47	−3.51	1,860	104	100	1,656
Oct. 21–22	9.09	(.94)	10.97	−2.82	2,253	(126)	88	2,039
Oct. 22–23	8.56	(.94)	9.84	−2.22	1,571	(126)	79	1,366
Oct. 23–24	10.06	(.94)	11.53	−2.41	2,009	(126)	92	1,791
Oct. 24–25	12.02	(.94)	10.38	+ .70	2,227	(126)	83	2,018
Oct. 25–26	7.37	(.94)	10.25	−3.82	1,361	(126)	82	1,153
Oct. 26–27	10.47	(.94)	11.13	−1.60	2,000	(126)	89	1,785
Oct. 27–28	8.56	(.94)	10.70	−3.08	1,790	(126)	86	1,578
Oct. 28–29	[1]16.01	....	....	....	[1]4,057	(126)	(73)	3,858
Oct. 29–30	11.10	(.94)	7.54	+2.62	1,904	(126)	60	1,718
Av. Oct. 15–30	10.64	....	10.81	....	....	....	....	1,855
Oct. 30–31	10.65	(.94)	10.70	− .99	1,456	(126)	86	1,244
Oct. 31–Nov. 1	8.34	1.06	10.28	−3.00	1,527	147	82	1,298
Nov. 1– 2	8.89	1.06	10.99	−3.16	1,478	147	88	1,243
Nov. 2– 3	9.13	1.06	11.03	−2.96	1,618	147	88	1,383
Nov. 3– 4	8.33	1.06	10.49	−3.22	1,683	147	84	1,452
Nov. 4– 5	8.30	(.92)	10.62	−3.24	1,740	(130)	85	1,525
Nov. 5– 6	8.97	(.92)	9.73	−1.68	1,384	(130)	78	1,176
Nov. 6– 7	7.84	(.92)	9.83	−2.91	1,545	(130)	79	1,336
Nov. 7– 8	8.88	(.92)	10.95	−2.99	1,875	(130)	88	1,657
Nov. 8– 9	6.26	(.92)	10.58	−5.24	1,290	(130)	85	1,075
Nov. 9–10	7.81	(.92)	8.90	−2.01	1,361	(130)	71	1,160
Nov. 10–11	8.70	(.92)	10.68	−2.90	1,548	(130)	85	1,333
Nov. 11–12	[1]15.58	....	....	....	[1]3,647	(130)	(76)	3,441
Av. Oct. 30–Nov. 12	9.05	....	10.40	....	....	....	....	1,486
Nov. 12–13	7.59	.78	8.32	−1.51	1,655	113	67	1,475
Nov. 13–14	11.19	.78	8.86	+1.55	1,806	113	71	1,622
Nov. 14–15	10.83	.78	10.61	− .56	1,692	113	85	1,494
Nov. 15–16	7.85	.78	10.20	−3.13	1,485	113	82	1,290
Nov. 16–17	9.47	.78	11.75	−3.06	1,346	113	94	1,139
Nov. 17–18	8.67	.78	11.65	−3.76	1,739	113	93	1,533
Nov. 18–19	7.41	(.87)	10.53	−3.99	1,374	(126)	84	1,164
Nov. 19–20	9.97	(.87)	9.90	− .80	1,919	(126)	79	1,714
Nov. 20–21	5.29	(.87)	9.98	−5.56	1,317	(126)	80	1,111
Nov. 21–22	6.01	(.87)	10.45	−5.31	1,453	(126)	84	1,243
Nov. 22–23	7.57	(.87)	11.39	−4.69	1,711	(126)	91	1,494
Nov. 23–24	7.85	(.87)	8.36	−1.38	1,744	(126)	67	1,551
Nov. 24–25	8.54	(.87)	10.24	−2.57	1,633	(126)	82	1,425
Nov. 25–26	[1]12.38	....	....	....	[1]3,063	(126)	(74)	2,863
Nov. 26–27	9.67	(.87)	8.09	+ .71	1,778	(126)	65	1,587
Nov. 27–28	8.93	(.87)	9.54	−1.48	1,596	(126)	76	1,394
Nov. 28–29	6.64	(.87)	10.87	−5.10	1,584	(126)	87	1,371
Av. Nov. 12–29	8.58	....	10.05	....	....	....	....	1,498

[1] Computed; see table 33, p. 269.

TABLE 58.—*Nitrogen balance and energy available to body*—RONALD T. VEAL—continued.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1917—*continued.*	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Reduced diet—*cont.*								
Nov. 29–30	......	......	10.70	......	......	......	......	......
Nov. 30–Dec. 1	......	......	8.84	......	......	......	......	......
Dec. 1– 2	......	......	7.33	......	......	......	......	......
Dec. 2– 3	......	......	......	......	......	......	......	......
Dec. 3– 4	4.39	(.87)	7.62	−4.10	990	(126)	61	803
Dec. 4– 5	10.18	(.87)	10.46	−1.15	1,734	(126)	84	1,524
Dec. 5– 6	8.19	(.87)	9.72	−2.40	1,618	(126)	78	1,414
Dec. 6– 7	8.70	(.87)	10.79	−2.96	1,802	(126)	86	1,590
Dec. 7– 8	6.75	(.87)	11.61	−5.73	1,577	(126)	93	1,358
Dec. 8– 9	8.51	(.87)	10.26	−2.62	1,786	(126)	82	1,578
Dec. 9–10	[1]19.79	......	......	......	[1]4,586	(126)	(79)	4,381
Dec. 10–11	8.07	.95	9.44	−2.32	1,988	138	76	1,774
Dec. 11–12	9.81	.95	8.60	+ .26	1,929	138	69	1,722
Dec. 12–13	11.24	.95	11.68	−1.39	2,250	138	93	2,019
Dec. 13–14	9.40	.95	12.50	−4.05	1,871	138	100	1,633
Dec. 14–15	8.48	.95	9.37	−1.84	2,134	138	75	1,921
Dec. 15–16	10.51	(.95)	......	......	2,676	(138)	(82)	2,456
Dec. 16–17	8.61	(.95)	......	......	1,946	(138)	(82)	1,726
Dec. 17–18	10.90	(.95)	10.98	−1.03	1,975	(138)	88	1,749
Dec. 18–19	10.04	(.95)	11.12	−2.03	2,036	(138)	89	1,809
Dec. 19–20[2]	9.05	(.95)	8.97	− .87	1,965	(138)	72	1,755
Av. Dec. 3–20	9.57	......	10.22	......	......	......	......	1,836
1918.								
Jan. 7– 8	7.63	(1.14)	4.29	+2.20	1,290	(163)	34	1,093
Jan. 8– 9	9.37	(1.14)	8.50	− .27	1,743	(163)	68	1,512
Jan. 9–10	12.06	(1.14)	9.61	+1.31	2,013	(163)	77	1,773
Jan. 10–11	10.66	(1.14)	9.77	− .25	2,087	(163)	78	1,846
Jan. 11–12	13.26	(1.14)	10.65	+1.47	2,126	(163)	85	1,878
Jan. 12–13	8.46	(1.14)	10.71	−3.39	1,788	(163)	86	1,539
Jan. 13–14	[1]11.27	(1.14)	11.88	−1.75	[1]2,524	(163)	95	2,266
Jan. 14–15	5.76	1.14	7.74	−3.12	1,190	163	62	965
Av. Jan. 7–15	9.81	......	9.14	......	......	......	......	1,609
Jan. 15–16	10.77	1.14	7.39	+2.24	1,890	163	59	1,668
Jan. 16–17	9.99	1.14	12.49	−3.64	1,828	163	100	1,565
Jan. 17–18	11.66	1.14	11.53	−1.01	1,861	163	92	1,606
Jan. 18–19	13.41	1.14	12.16	+ .11	2,385	163	97	2,125
Jan. 19–20	10.95	1.14	11.73	−1.92	2,264	163	94	2,007
Jan. 20–21	11.39	1.14	11.76	−1.51	2,406	163	94	2,149
Jan. 21–22	8.28	1.14	9.94	−2.80	1,451	163	80	1,208
Jan. 22–23	10.12	1.14	10.35	−1.37	1,679	163	83	1,433
Jan. 23–24	14.74	1.14	12.56	+1.04	3,118	163	100	2,855
Jan. 24–25	8.43	1.14	11.52	−4.23	1,458	163	92	1,203
Jan. 25–26	10.97	1.14	9.76	+ .07	2,354	163	78	2,113
Jan. 26–27	10.51	1.14	11.45	−2.08	2,163	163	92	1,908
Jan. 27–28	8.75	1.14	11.65	−4.04	1,686	163	93	1,430
Jan. 28–29	12.44	1.14	10.07	+1.23	2,294	163	81	2,050
Jan. 29–30	11.25	1.14	10.06	+ .05	2,098	163	80	1,855
Jan. 30–31	12.27	(1.14)	9.19	+1.94	2,805	(163)	74	2,568
Jan. 31–Feb. 1	12.82	(1.14)	11.62	+ .06	2,199	(163)	93	1,943
Feb. 1– 2	16.56	(1.14)	11.04	+4.38	2,969	(163)	88	2,718
Feb. 2– 3	10.46	(1.14)	11.81	−2.49	2,132	(163)	94	1,875
Av. Jan. 15–Feb. 3	11.36	......	10.95	......	......	......	......	1,909

[1] Computed see table 33, p. 269. [2] Dec. 20, 1917–Jan. 6, 1918 (inclusive), Christmas recess.

NITROGEN BALANCE AND ENERGY AVAILABLE TO BODY, SQUAD B.

TABLE 59.—*Nitrogen balance and energy available to body during period of reduced diet*—EDWARD M. FISHER.

Date.	Nitrogen per 24 hours in— Food.	Feces.	Urine.	Nitrogen balance.	Energy per 24 hours of— Food.	Feces.	Urine (N×8.0).	Net energy.
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8–9	7.67	(1.40)	9.49	−3.22	1,264	(145)	76	1,043
9–10	8.27	(1.40)	10.59	−3.72	1,482	(145)	85	1,252
10–11	8.04	(1.40)	10.23	−3.59	1,572	(145)	82	1,345
11–12	8.47	(1.40)	10.26	−3.19	1,584	(145)	82	1,357
12–13	9.22	(1.40)	10.93	−3.11	1,740	(145)	87	1,508
13–14	7.89	(1.40)	8.92	−2.43	1,676	(145)	71	1,460
14–15	10.09	(1.40)	11.10	−2.41	1,961	(145)	89	1,727
15–16	7.82	1.40	10.70	−4.28	1,506	145	86	1,275
16–17	7.64	1.40	8.63	−2.39	1,451	145	69	1,237
17–18	9.03	1.40	10.08	−2.45	1,461	145	81	1,235
18–19	8.44	1.40	8.91	−1.87	1,486	145	71	1,270
19–20	8.07	1.40	10.54	−3.87	1,816	145	84	1,587
20–21	8.88	1.40	10.22	−2.74	1,663	145	82	1,436
21–22	8.05	1.40	9.29	−2.64	1,584	145	74	1,365
22–23	8.66	1.40	9.58	−2.32	1,430	145	77	1,208
23–24	7.59	(1.40)	9.06	−2.87	1,554	(145)	72	1,337
24–25	9.05	(1.40)	8.08	− .43	1,768	(145)	65	1,558
25–26	8.78	(1.40)	......	......	1,571	(145)	(73)	1,353
26–27	7.91	(1.40)	9.98	−3.47	1,658	(145)	80	1,433
27–28	6.11	(1.40)	7.00	−2.29	1,615	(145)	56	1,414
Average	8.28	1.40	9.66	−2.80	1,592	145	77	1,370

TABLE 60.—*Nitrogen balance and energy available to body during period of reduced diet*—VICTOR H. HARTSHORN.

Date.	Nitrogen per 24 hours in— Food.	Feces.	Urine.	Nitrogen balance.	Energy per 24 hours of— Food.	Feces.	Urine (N×8.0).	Net energy.
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8–9	7.29	(0.74)	12.34	−5.79	1,198	(96)	99	1,003
9–10	8.27	(.74)	11.06	−3.53	1,474	(96)	88	1,290
10–11	8.04	(.74)	8.24	− .94	1,556	(96)	66	1,394
11–12	8.47	(.74)	10.89	−3.16	1,584	(96)	87	1,401
12–13	9.22	(.74)	10.28	−1.80	1,724	(96)	82	1,546
13–14	7.51	(.74)	9.43	−2.66	1,608	(96)	75	1,437
14–15	9.77	(.74)	11.37	−2.34	1,874	(96)	91	1,687
15–16	7.66	.74	12.31	−5.39	1,465	96	98	1,271
16–17	7.64	.74	10.87	−3.97	1,435	96	87	1,252
17–18	8.71	.74	11.22	−3.25	1,396	96	90	1,210
18–19	7.80	.74	10.07	−3.01	1,382	96	81	1,205
19–20	7.89	.74	8.84	−1.69	1,806	96	71	1,639
20–21	8.20	.74	11.20	−3.74	1,533	96	90	1,347
21–22	7.73	.74	11.75	−4.76	1,527	96	94	1,337
22–23	8.25	.74	11.18	−3.67	1,358	96	89	1,173
23–24	7.26	(.74)	8.95	−2.43	1,492	(96)	72	1,324
24–25	8.73	(.74)	9.92	−1.93	1,710	(96)	79	1,535
25–26	8.78	(.74)	10.95	−2.91	1,555	(96)	88	1,371
26–27	7.22	(.74)	10.51	−4.03	1,481	(96)	84	1,301
27–28	6.11	(.74)	7.15	−1.78	1,599	(96)	57	1,446
Average	8.03	.74	10.43	−3.14	1,538	96	83	1,358

TABLE 61.—*Nitrogen balance and energy available to body during period of reduced diet*—KARL Z. HOWLAND.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8– 9............	7.67	(0.84)	10.12	−3.29	1,272	(110)	81	1,081
9–10............	7.76	(.84)	11.52	−4.60	1,411	(110)	92	1,209
10–11............	8.04	(.84)	10.28	−3.08	1,572	(110)	82	1,380
11–12............	8.15	(.84)	8.89	−1.58	1,535	(110)	71	1,354
12–13............	9.71	(.84)	11.61	−2.74	1,714	(110)	93	1,511
13–14............	7.89	(.84)	8.99	−1.94	1,676	(110)	72	1,494
14–15............	10.09	(.84)	11.93	−2.68	1,961	(110)	95	1,756
15–16............	7.82	.84	9.96	−2.98	1,506	110	80	1,316
16–17............	7.64	.84	11.21	−4.41	1,451	110	90	1,251
17–18............	9.03	.84	12.31	−4.12	1,461	110	98	1,253
18–19............	8.44	.84	12.36	−4.76	1,497	110	99	1,288
19–20............	8.07	.84	12.03	−4.80	1,816	110	96	1,610
20–21............	8.16	.84	11.63	−4.31	1,535	110	93	1,332
21–22............	7.89	.84	10.66	−3.61	1,575	110	85	1,380
22–23............	8.66	.84	10.45	−2.63	1,430	110	84	1,236
23–24............	7.59	(.84)	11.69	−4.94	1,562	(110)	94	1,358
24–25............	9.05	(.84)	10.11	−1.90	1,784	(110)	81	1,593
25–26............	8.78	(.84)	11.18	−3.24	1,571	(110)	89	1,372
26–27............	7.91	(.84)	11.09	−4.02	1,658	(110)	89	1,459
27–28............	6.13	(.84)	9.31	−4.02	1,594	(110)	74	1,410
Average.........	8.22	.84	10.87	−3.48	1,579	110	87	1,382

TABLE 62.—*Nitrogen balance and energy available to body during period of reduced diet*—ROBERT L. HAMMOND.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8– 9............	7.34	(0.53)	14.21	−7.40	1,015	(79)	114	882
9–10............	6.10	(.53)	14.74	−9.17	839	(79)	118	1,642
10–11............	8.28	(.53)	12.70	−4.95	1,401	(79)	102	1,220
11–12............	7.81	(.53)	12.99	−5.71	1,500	(79)	104	1,317
12–13............	8.35	(.53)	12.06	−4.24	1,576	(79)	96	1,401
13–14............	7.57	(.53)	8.95	−1.91	1,564	(79)	72	1,413
14–15............	10.32	(.53)	13.33	−3.54	1,672	(79)	107	1,486
15–16............	6.90	.53	10.51	−4.14	1,596	79	84	1,433
16–17............	6.45	.53	10.82	−4.90	1,349	79	87	1,183
17–18............	7.71	.53	10.36	−3.18	1,269	79	83	1,107
18–19............	7.17	.53	10.44	−3.80	1,289	79	84	1,126
19–20............	7.48	.53	10.22	−3.27	1,650	79	82	1,489
20–21............	8.12	.53	12.01	−4.42	1,541	79	96	1,366
21–22............	7.70	.53	9.68	−2.51	1,475	79	77	1,319
22–23............	7.21	.53	12.67	−5.99	1,297	79	101	1,117
23–24............	7.61	(.53)	13.44	−6.36	1,454	(79)	108	1,267
24–25............	7.99	(.53)	9.77	−2.31	1,681	(79)	78	1,524
25–26............	7.91	(.53)	11.91	−4.53	1,427	(79)	95	1,253
26–27............	6.32	(.53)	10.59	−4.80	1,493	(79)	85	1,329
27–28............	6.54	(.53)	8.91	−2.90	1,555	(79)	71	1,405
Average.........	7.54	.53	11.52	−4.50	1,432	79	92	1,261

TABLE 63.—*Nitrogen balance and energy available to body during period of reduced diet—* HAROLD L. KIMBALL.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8–9	7.29	(0.88)	10.75	−4.34	1,214	(120)	86	1,008
9–10	7.89	(.88)	8.84	−1.83	1,432	(120)	71	1,241
10–11	7.88	(.88)	9.27	−2.27	1,539	(120)	74	1,345
11–12	8.55	(.88)	9.64	−1.97	1,544	(120)	77	1,347
12–13	9.22	(.88)	9.65	−1.31	1,740	(120)	77	1,543
13–14	7.89	(.88)	9.59	−2.58	1,676	(120)	77	1,479
14–15	10.09	(.88)	10.23	−1.02	1,961	(120)	82	1,759
15–16	7.82	.88	9.66	−2.72	1,506	120	77	1,309
16–17	7.64	.88	6.79	− .03	1,451	120	54	1,277
17–18	9.03	.88	10.55	−2.40	1,461	120	84	1,257
18–19	8.79	.88	7.76	+ .15	1,594	120	62	1,412
19–20	9.75	.88	11.38	−2.51	2,121	120	91	1,910
20–21	8.16	.88	9.75	−2.47	1,535	120	78	1,337
21–22	8.05	.88	9.11	−1.94	1,592	120	73	1,399
22–23	8.66	.88	8.34	− .56	1,430	120	67	1,243
23–24	7.59	(.88)	8.78	−2.07	1,554	(120)	70	1,364
24–25	9.05	(.88)	5.95	+2.22	1,768	(120)	48	1,600
25–26	8.78	(.88)	7.10	+ .80	1,579	(120)	57	1,402
26–27	9.48	(.88)	8.30	+ .30	2,109	(120)	66	1,923
27–28	7.17	(.88)	12.25	−5.96	1,672	(120)	98	1,454
Average	8.44	.88	9.18	−1.63	1,624	120	73	1,430

TABLE 64.—*Nitrogen balance and energy available to body during period of reduced diet—* ROBERT H. LONG.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8–9	7.29	(0.63)	9.83	−3.17	1,198	(91)	79	1,028
9–10	8.27	(.63)	9.62	−1.98	1,490	(91)	77	1,322
10–11	8.04	(.63)	8.84	−1.43	1,572	(91)	71	1,410
11–12	8.15	(.63)	8.13	− .61	1,535	(91)	65	1,379
12–13	8.90	(.63)	8.80	− .53	1,691	(91)	70	1,530
13–14	7.89	(.63)	11.08	−3.82	1,676	(91)	89	1,496
14–15	10.09	(.63)	9.82	− .36	1,961	(91)	79	1,791
15–16	7.82	.63	11.21	−4.02	1,506	91	90	1,325
16–17	7.64	.63	5.80	+1.21	1,451	91	46	1,314
17–18	9.03	.63	9.40	−1.00	1,461	91	75	1,295
18–19	8.44	.63	8.68	− .87	1,486	91	69	1,326
19–20	8.07	.63	11.03	−3.59	1,816	91	88	1,637
20–21	8.16	.63	12.47	−4.94	1,535	91	100	1,344
21–22	8.05	.63	9.86	−2.44	1,592	91	79	1,422
22–23	8.66	.63	10.48	−2.45	1,430	91	84	1,255
23–24	7.59	(.63)	9.26	−2.30	1,554	(91)	74	1,389
24–25	9.05	(.63)	6.81	+1.61	1,768	(91)	54	1,623
25–26	8.78	(.63)	11.15	−3.00	1,571	(91)	89	1,391
26–27	7.65	(.63)	7.32	− .30	1,608	(91)	59	1,458
27–28	6.11	(.63)	10.64	−5.16	1,615	(91)	85	1,439
Average	8.18	.63	9.51	−1.96	1,576	91	76	1,409

TABLE 65.—*Nitrogen balance and energy available to body during period of reduced diet*—JOHN SCHRACK.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8–9	7.29	(0.88)	6.71	− .30	1,214	(117)	54	1,043
9–10	8.08	(.88)	9.89	−2.69	1,461	(117)	79	1,265
10–11	7.72	(.88)	9.25	−2.41	1,522	(117)	74	1,331
11–12	8.31	(.88)	10.02	−2.59	1,559	(117)	80	1,362
12–13	9.22	(.88)	10.12	−1.78	1,740	(117)	81	1,542
13–14	7.89	(.88)	10.08	−3.07	1,676	(117)	81	1,478
14–15	10.09	(.88)	10.22	−1.01	1,961	(117)	82	1,762
15–16	7.82	.88	9.38	−2.44	1,506	117	75	1,314
16–17	7.64	.88	10.21	−3.45	1,459	117	82	1,260
17–18	9.03	.88	8.37	− .22	1,461	117	67	1,277
18–19	8.44	.88	9.92	−2.36	1,494	117	79	1,298
19–20	8.07	.88	8.76	−1.57	1,816	117	70	1,629
20–21	8.88	.88	10.42	−2.42	1,671	117	83	1,471
21–22	8.05	.88	22.08	−7.13	1,600	117	177	2,627
22–23	8.66	.88			1,438	117		
23–24	7.59	(.88)	10.40	−3.69	1,554	(117)	83	1,354
24–25	9.05	(.88)	8.73	− .56	1,768	(117)	70	1,581
25–26	8.78	(.88)	9.22	−1.32	1,571	(117)	74	1,380
26–27	7.91	(.88)	10.25	−3.22	1,658	(117)	82	1,459
27–28	6.13	(.88)	10.98	−5.73	1,595	(117)	88	1,390
Average	8.23	.88	9.75	−2.40	1,586	117	78	1,391

TABLE 66.—*Nitrogen balance and energy available to body during period of reduced diet*—ALFRED LIVINGSTONE.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8–9	7.67	(0.68)	17.41	−10.42	1,256	(108)	139	1,009
9–10	8.27	(.68)	11.91	−4.32	1,490	(108)	95	1,287
10–11	8.04	(.68)	12.40	−5.04	1,564	(108)	99	1,357
11–12	8.47	(.68)	11.92	−4.13	1,576	(108)	95	1,373
12–13	9.22	(.68)	12.72	−4.18	1,724	(108)	102	1,514
13–14	7.89	(.68)	11.97	−4.76	1,660	(108)	96	1,456
14–15	10.09	(.68)	10.41	−1.00	1,945	(108)	83	1,754
15–16	7.82	.68	....	....	1,498	108	87	1,303
16–17	7.64	.68	11.33	−4.37	1,443	108	91	1,244
17–18	9.03	.68	11.42	−3.07	1,445	108	91	1,246
18–19	8.44	.68	12.76	−5.00	1,486	108	102	1,276
19–20	8.07	.68	11.14	−3.75	1,816	108	89	1,619
20–21	8.88	.68	11.47	−3.27	1,655	108	92	1,455
21–22	8.05	.68	11.65	−4.28	1,592	108	93	1,391
22–23	8.66	.68	11.76	−3.78	1,430	108	94	1,228
23–24	7.59	(.68)	11.25	−4.34	1,546	(108)	90	1,348
24–25	9.05	(.68)	11.51	−3.14	1,752	(108)	92	1,552
25–26	8.78	(.68)	11.21	−3.11	1,563	(108)	90	1,365
26–27	7.91	(.68)	10.23	−3.00	1,658	(108)	82	1,468
27–28	6.38	(.68)	10.06	−4.36	1,657	(108)	80	1,469
Average	8.30	.68	11.82	−4.17	1,588	08	94	1,386

TABLE 67.—*Nitrogen balance and energy available to body during period of reduced diet*—CHESTER D. SNELL.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8– 9	7.29	(0.99)	12.01	−5.71	1,214	(116)	96	1,002
9–10	8.11	(.99)	12.12	−5.00	1,465	(116)	97	1,252
10–11	8.04	(.99)	10.60	−3.55	1,572	(116)	85	1,371
11–12	8.47	(.99)	10.91	−3.43	1,584	(116)	87	1,381
12–13	9.22	(.99)	10.99	−2.76	1,740	(116)	88	1,536
13–14	7.89	(.99)	8.46	−1.56	1,676	(116)	68	1,492
14–15	10.09	(.99)	11.31	−2.21	1,961	(116)	90	1,755
15–16	7.82	.99	......	......	1,506	116	(90)	1,300
16–17	7.64	.99	11.10	−4.45	1,451	116	89	1,246
17–18	9.03	.99	10.69	−2.65	1,461	116	86	1,259
18–19	8.44	.99	10.67	−3.22	1,486	116	85	1,285
19–20	8.07	.99	9.83	−2.75	1,816	116	79	1,621
20–21	8.52	.99	10.87	−3.34	1,599	116	87	1,396
21–22	8.05	.99	9.88	−2.82	1,592	116	79	1,397
22–23	8.66	.99	9.73	−2.06	1,430	116	78	1,236
23–24	7.59	(.99)	10.49	−3.89	1,562	(116)	84	1,362
24–25	9.05	(.99)	9.84	−1.78	1,760	(116)	79	1,565
25–26	8.78	(.99)	9.71	−1.92	1,579	(116)	78	1,385
26–27	8.80	(.99)	10.14	−2.33	1,925	(116)	81	1,728
27–28	7.82	(.99)	7.46	− .63	1,849	(116)	60	1,673
Average	8.37	.99	10.36	−2.95	1,611	116	83	1,412

TABLE 68.—*Nitrogen balance and energy available to body during period of reduced diet*—GEORGE H. THOMPSON.

Date.	Nitrogen per 24 hours in—			Nitrogen balance.	Energy per 24 hours of—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine (N×8.0).	
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8– 9	7.29	(1.20)	7.84	−1.75	1,214	(138)	63	1,013
9–10	8.11	(1.20)	10.03	−3.12	1,465	(138)	80	1,247
10–11	8.04	(1.20)	11.13	−4.29	1,572	(138)	89	1,345
11–12	8.47	(1.20)	11.64	−4.37	1,584	(138)	93	1,353
12–13	8.90	(1.20)	11.03	−3.33	1,691	(138)	88	1,465
13–14	7.89	(1.20)	10.10	−3.41	1,676	(138)	81	1,457
14–15	10.09	(1.20)	11.15	−2.26	1,961	(138)	89	1,734
15–16	7.82	1.20	11.15	−4.53	1,506	138	89	1,279
16–17	7.64	1.20	10.71	−4.27	1,451	138	86	1,227
17–18	9.03	1.20	10.32	−2.49	1,461	138	83	1,240
18–19	8.44	1.20	10.17	−2.93	1,486	138	81	1,267
19–20	8.07	1.20	12.07	−5.20	1,816	138	97	1,581
20–21	8.88	1.20	11.27	−3.59	1,663	138	90	1,435
21–22	8.05	1.20	9.96	−3.11	1,592	138	80	1,374
22–23	8.66	1.20	10.27	−2.81	1,430	138	82	1,210
23–24	7.59	(1.20)	12.83	−6.44	1,554	(138)	103	1,313
24–25	9.05	(1.20)	10.91	−3.06	1,768	(138)	87	1,543
25–26	8.78	(1.20)	10.43	−2.85	1,571	(138)	83	1,350
26–27	7.91	(1.20)	11.15	−4.44	1,658	(138)	89	1,431
27–28	6.11	(1.20)	10.59	−5.68	1,615	(138)	85	1,392
Average	8.24	1.20	10.74	−3.70	1,587	138	86	1,363

TABLE 69.—*Nitrogen balance and energy available to body during period of reduced diet*—FLOYD M. VAN WAGNER.

Date.	Nitrogen per 24 hours in— Food.	Feces.	Urine.	Nitrogen balance.	Energy per 24 hours of— Food.	Feces.	Urine (N×8.0).	Net energy.
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8–9	7.29	(0.99)	11.42	−5.12	1,214	(126)	91	997
9–10	8.27	(.99)	7.79	− .51	1,490	(126)	62	1,302
10–11	8.04	(.99)	10.73	−3.68	1,572	(126)	86	1,360
11–12	8.47	(.99)	10.68	−3.20	1,584	(126)	85	1,373
12–13	9.22	(.99)	11.25	−3.02	1,740	(126)	90	1,524
13–14	7.89	(.99)	8.80	−1.90	1,676	(126)	70	1,480
14–15	10.09	(.99)	10.37	−1.27	1,961	(126)	83	1,752
15–16	7.17	.99	10.49	−4.31	1,448	126	84	1,238
16–17	7.64	.99	9.82	−3.17	1,451	126	79	1,246
17–18	9.03	.99	10.68	−2.64	1,461	126	85	1,250
18–19	8.44	.99	11.61	−4.16	1,486	126	93	1,267
19–20	8.07	.99	9.41	−2.33	1,816	126	75	1,615
20–21	8.16	.99	11.67	−4.50	1,535	126	93	1,316
21–22	8.05	.99	9.20	−2.14	1,592	126	74	1,392
22–23	8.66	.99	8.61	− .94	1,438	126	69	1,243
23–24	7.59	(.99)	10.06	−3.46	1,554	(126)	80	1,348
24–25	9.05	(.99)	9.16	−1.10	1,768	(126)	73	1,569
25–26	8.78	(.99)	9.46	−1.67	1,579	(126)	76	1,377
26–27	6.19	(.99)	10.23	−5.03	1,429	(126)	82	1,221
27–28	6.11	(.99)	7.66	−2.54	1,615	(126)	61	1,428
Average	8.11	.99	9.96	−2.83	1,560	126	80	1,365

TABLE 70.—*Nitrogen balance and energy available to body during period of reduced diet*—ELTON L. WILLIAMS.

Date.	Nitrogen per 24 hours in— Food.	Feces.	Urine.	Nitrogen balance.	Energy per 24 hours of— Food.	Feces.	Urine (N×8.0).	Net energy.
1918.	*gm.*	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 8–9	7.29	(0.92)	12.58	−6.21	1,206	(132)	101	973
9–10	8.27	(.92)	11.98	−4.63	1,490	(132)	96	1,262
10–11	8.04	(.92)	9.56	−2.44	1,572	(132)	76	1,364
11–12	8.47	(.92)	12.85	−5.30	1,584	(132)	103	1,349
12–13	10.03	(.92)	12.09	−2.98	1,736	(132)	97	1,507
13–14	7.89	(.92)	10.04	−3.07	1,676	(132)	80	1,464
14–15	10.09	(.92)	12.01	−2.84	1,961	(132)	96	1,733
15–16	7.82	.92	11.96	−5.06	1,506	132	96	1,278
16–17	7.64	.92	11.21	−4.49	1,451	132	90	1,229
17–18	9.03	.92	11.15	−3.04	1,461	132	87	1,240
18–19	8.44	.92	10.01	−2.49	1,486	132	80	1,274
19–20	8.07	.92	11.24	−4.09	1,816	132	90	1,594
20–21	10.89	.92	....	....	1,755	132	(88)	1,535
21–22	7.73	.92	10.69	−3.88	1,543	132	86	1,325
22–23	8.66	.92	11.24	−3.50	1,430	132	90	1,208
23–24	7.59	(.92)	11.77	−5.10	1,554	(132)	94	1,328
24–25	9.05	(.92)	10.25	−2.12	1,776	(132)	82	1,562
25–26	8.78	(.92)	12.39	−4.53	1,579	(132)	99	1,348
26–27	7.91	(.92)	10.56	−3.57	1,666	(132)	84	1,450
27–28	6.13	(.92)	5.68	− 47	1,603	(132)	45	1,426
Average	8.39	.92	11.01	−3.67	1,593	132	88	1,372

The irregularities in the nitrogen intake have been pointed out in a previous section, as shown for the individual subjects at the beginning of the observations and for 2 weeks in December and from the average for the whole squad. These irregularities are strikingly shown in tables 46 to 58. The estimated intakes of nitrogen and energy for the uncontrolled days are also included in these tables, but are indicated by footnotes, since their mathematical accuracy is in doubt. They stand out prominently as the intakes of both nitrogen and calories are larger than on either the preceding or following days. The gain or loss of nitrogen for these uncontrolled days is not computed except for January 13–14, 1918. The estimations for nitrogen intake are, however, considered of sufficient accuracy to be included in any general averages which appear in the tables. Unfortunately, owing to the extremely cold winter and unsatisfactory transportation, some of the samples of urine for December 15, 16, and 17 were frozen, and hence the values for these days can not be given, and no estimate has been attempted. These days are omitted from any general consideration of the nitrogen balance. Although it was impossible to obtain the fecal nitrogen for the entire period, reference to table 37 (p. 293), and, indeed, tables 46 to 58, shows that the separation of feces was made with sufficient frequency to give a fairly uniform picture of the probable fecal nitrogen excretion for the whole experiment. In the detailed tables the interpolated values are placed in parentheses, all other values for feces being those actually determined. These determined values usually represent the average for a period of collection of feces of 3 to 16 days.

The general picture presented by every member of Squad A is a great predominance of minus figures for the nitrogen balance, after the first three preliminary days of unrestricted diet. Plus values rarely appear, except in the latter part of December and the latter part of January. Throughout the period of loss in weight there was evidently a pronounced tendency for each subject to lose nitrogen. During December, when an attempt was made to supply a sufficient number of calories to secure weight maintenance, the frequent appearance of positive figures indicates that with the higher caloric intake there was a smaller loss of nitrogen with a tendency towards equilibrium. During the last week in January this is particularly noticeable. A general statement may thus be made that for practically the entire experiment, save for these two periods, the subjects were losing body nitrogen, as shown by a comparison of the fecal and urinary nitrogen with the nitrogen in the food.

The total losses of nitrogen from the body shown by these men prior to January 28 are of interest, since in the last week of the experiment the caloric intake was considerably increased to hold the body-weight. The total losses of nitrogen from October 4, the initial day of the re-

duced diet, until January 27, inclusive, without regard to the cutaneous loss or to the uncontrolled days, has been computed for all of the subjects in Squad A and recorded in table 71. Special attention must

TABLE 71.—*Total loss of nitrogen and average daily loss of nitrogen, Squad A, October 4 to January 27, inclusive.*

Subject.	Total loss of nitrogen.	No. of days.	Av. loss of nitrogen per day.
	gm.		*gm.*
Bro......	153.48	83	1.85
Can......	155.77	84	1.85
Fre......	32.29	20	1.61
Kon.....	233.08	57	4.09
Gar......	168.95	86	1.96
Gul......	162.45	86	1.89
Mon.....	134.07	86	1.56
Moy.....	230.31	83	2.77
Pea......	206.14	86	2.40
Pec......	252.85	87	2.91
Spe......	130.15	61	2.13
Tom.....	48.66	78	0.62
Vea......	159.70	86	1.86

be paid to the number of days that the subjects were actually studied. Thus we have for *Fre* but 20 days, for *Kon*, 57 days, for *Spe*, 61 days, and for *Tom*, 78 days. The other men were studied from 83 to 87 days. Disregarding the value for *Fre*, we find that with the members of Squad A, who were longest studied, the total nitrogen loss ranges from a minimum of 48.66 grams with *Tom* to a maximum of 252.85 grams with *Pec*. Every member of the squad, other than *Fre* and *Tom*, lost more than 130 grams in this period, and 3 lost more than 230 grams. The average loss of nitrogen per day is given in the last column of the table and shows a minimum value of 0.62 gram with *Tom* and a maximum value of 4.09 grams with *Kon*. At least 10 men showed losses of over 1.8 grams per day. When it is considered that these losses continued in most instances for a period of 80 days or more, the total loss is really remarkable. The small loss recorded for *Fre* is accounted for by the fact that he was but 20 days on diet and needs no further discussion. The largest average loss, that of *Kon*, is possibly explained by the fact that he began late and was purposely put upon a very restricted diet in order to reduce the body-weight as rapidly as possible. The small loss with *Tom* is, in part, explained by his small body-weight as compared with the other subjects. His activity was also the least, and the total reduction in diet was not so low per kilogram of body-weight as with many of the other men. Furthermore, on account of his feeling of *malaise* throughout January, resulting from an operation during the Christmas recess, a rigid dietetic restriction did not seem possible with him. The difficulty experienced in lowering his body-

weight has been frequently commented upon in other parts of this report. The average loss per day for all men is, excluding *Fre*, 2.16 grams.

The losses in nitrogen for Squad B are given in a similar manner in table 72. These values also disregard cutaneous losses, which, probably, in this case should not be disregarded, since we have no compensating excess food to deal with. Although the nitrogen balance figures for Squad B are given in detail in tables 59 to 70, it must be borne in mind that the conditions are altogether different from those with Squad A. Squad A had, to be sure, a reduced diet, but Squad B was given what may be termed a greatly reduced diet, that is, a diet certainly less than half of their normal diet maintenance requirements. No complicating circumstances such as uncontrolled days enter into their values. The total nitrogen in the food intake is extraordinarily low, averaging 8.19 grams, and the average net energy 1,375 calories. With but few exceptions, the daily values for the nitrogen balance for the individual subjects are minus. (See tables 59 to 70.) Losses of 9 or 10 grams of nitrogen are occasionally noted and not infrequently 5, 6, and 7 grams. In general, the losses are much more pronounced than they were in any stage of the experiment with Squad A. The average daily loss per man as given in table 72 is 3.10 grams of nitrogen. This indicates the severity of the curtailment of the diet, for it is greater than the average loss with Squad A which was but 2.30 grams per day.

TABLE 72.—*Nitrogen balance and energy available to body during period of reduced diet—Squad B.*

[Averages per day, January 7 to 28, 1918.]

Subject.	Nitrogen in—			Loss of nitrogen.	Energy in—			Net energy.
	Food.	Feces.	Urine.		Food.	Feces.	Urine.	
	gm.	*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*	*cals.*
Fis.....	8.28	1.40	9.66	2.80	1,592	145	77	1,370
Har....	8.03	.74	10.43	3.14	1,538	96	83	1,358
How....	8.22	.84	10.87	3.48	1,579	110	87	1,382
Ham...	7.54	.53	11.52	4.50	1,432	79	92	1,261
Kim....	8.44	.88	9.18	1.63	1,624	120	73	1,430
Lon....	8.18	.63	9.51	1.96	1,576	91	76	1,409
Sch.....	8.23	.88	9.75	2.40	1,586	117	78	1,391
Liv.....	8.30	.68	11.82	4.17	1,588	108	94	1,386
Sne.....	8.37	.99	10.36	2.95	1,611	116	83	1,412
Tho....	8.24	1.20	10.74	3.70	1,587	138	86	1,363
Van....	8.11	.99	9.96	2.83	1,570	126	80	1,365
Wil.....	8.39	.92	11.01	3.67	1,593	132	88	1,372
Av...	8.19	....	....	3.10	....	....	....	1,375

If one considers the individual balance tables for Squad A with a general view to the appearance of plus signs and the magnitude of minus values in the nitrogen balance and compares these figures with

the energy balance showing the average net energy available to the body in the several periods of the experiment, it will be seen that there is a very close correlation between nitrogen loss and low net energy. In general, when the net energy is low, the minus figures appear in large proportion and the loss in nitrogen increases.

With Squad B the reduction in diet was so great, and the total energy available to the body was so small, that the period was not sufficiently long to bring the body-weight to a level and thus permit the drawing of definite quantitative comparisons between the total caloric intake and the average nitrogen loss. It is clear, however, that the large losses found with these subjects, taken into consideration with the small caloric intake, are fully in accord with the general picture shown for Squad A.

There seems to be, therefore, some very definite relationship between the total energy intake and the nitrogen loss, a relationship most strikingly shown with Squad A. Indeed, it is not impossible to conceive that were one to adjust the diet so as to obtain nitrogen equilibrium one would also have energy equilibrium.[1] This, of course, was by no means clearly and definitely proved, but is strongly suggested by the figures in the individual tables for the several men.

Since the total caloric intake on the average bears a very close relationship to the body-weight curve, as shown in figures 57 to 68, we may reason that if the diet had been adjusted to secure nitrogen equilibrium without regard to the calories, the body-weight would have likewise reached equilibrium. In other words, the loss of nitrogen is directly associated with a loss of body-material, not simply nitrogenous material but that which results in an ultimate material lowering of the body-weight.

That it would be possible for a group of men to lose from 130 to 250 grams of nitrogen over a period of this time and not show profound disturbance would, a decade ago, hardly have been believed. Experience with a man who fasted 31 days in the Nutrition Laboratory and during this time lost 277 grams of nitrogen has, however, given us a different impression of the significance of the so-called nitrogen "balance" or the loss of nitrogen from the body. It is hardly probable that any great amount of organized body-tissue is disintegrated in this loss of nitrogen. We regret that experimental exigencies were such that we could not determine the blood nitrogen and its apportionment. This must remain one of the problems to be solved subsequently. It seems very clear, however, that when the calories are deficient and the body must draw upon its store for caloric material, there is simultaneously a considerable loss of nitrogen. The potential energy of the protein corresponding to the nitrogen thus lost can not account for any appreciable percentage of the energy lost from the

[1] Klemperer, Zeitschr. f. klin Med., 1889, **16**, p. 597.

body or furnished by the body to make up the deficiency in caloric intake. But the nitrogen thus lost is undoubtedly an appreciable percentage of the total body-nitrogen. A subsequent discussion of the energy transformations of these men shows that a very great lowering of energy transformation takes place simultaneously with the loss in body-weight and the loss of this excess nitrogen. Our suggestion is that the nitrogen thus lost comes from the fluid bathing the cells, and is in some form which stimulates them to their normal level of activity. We have, therefore, loss of body-nitrogen closely correlated with general loss in body-weight and with reduced intake of energy.

It is to be remembered that with these men the loss in body-weight resulted in general from a deficiency in the intake of food. In certain cases this deficiency of intake was undoubtedly supplemented in its effect upon the body-weight loss by excessive physical exercise. An interesting problem immediately suggests itself as to what would have been the influence of the nitrogen loss had the caloric intake remained constant and had the body-weight loss been produced by excessive physical exercise alone, a problem of far-reaching physiological importance and possibly of considerable athletic significance.

CORRECTION OF PRELIMINARY STATEMENTS.

It is necessary at this time to point out an error made recently by us in a preliminary report of this research before the National Academy of Sciences in Washington, D. C. In this report it was stated that "the nitrogen output per day at the maintenance diet of 2,300 net calories was about 9 grams. A control group of 12 men, living substantially the same life and eating in the same dining-room, but with unrestricted diet, showed a nitrogen output of 16 to 17 grams per day."[1] Three serious errors appeared in this statement:

(1) The caloric intake at the lowest weight level was not 2,300 calories, but 1,950 calories.

(2) An examination of the nitrogen balance tables (tables 46 to 58) shows clearly that the value of 9 grams for the nitrogen excretion at the lowest level of weight maintenance (December 3 to February 3) is too small, and that it should be 10.5 grams (see table 73). While one subject, *Tom*, excreted only 7.7 grams, another subject, *Can*, excreted invariably over 11 grams (see table 35) and averaged 12.0 grams.

(3) The statement that a control group of 12 men excreted from 16 to 17 grams is erroneous in that these figures represent not the nitrogen excretion but the nitrogen of the food. By reference to table 32 it can be seen that the nitrogen intake of a control group of 12 men ranged in 5 days from 17.06 to 20.80 grams, with an average of 18.46 grams. As has already been stated, our information regarding the normal excre-

[1] Benedict and Roth, Proc. Nat. Acad. Sci., 1918, 4, p. 151.

tion of nitrogen of our subjects is unfortunately scanty, but table 45 shows that the nitrogen excretion of a group of men on February 11 to 16, 1918, with normal unrestricted diet, averaged 13.97 grams.

TABLE 73.—*Average daily nitrogen excretion at low weight-level—Squad A.*

Subject.	Nitrogen excretion per 24 hrs.	Subject.	Nitrogen excretion per 24 hrs.
	gm.		*gm.*
Bro......	10.2	Moy.....	11.4
Can......	12.0	Pea......	11.1
Kon.....	11.6	Pec......	10.8
Gar......	10.2	Tom.....	7.7
Gul......	9.2	Vea......	10.1
Mon.....	11.5		
		Av...	10.5

NITROGEN OUTPUT OF MEDICAL STUDENTS.

Subsidiary evidence regarding the normal nitrogen excretion is supplied by the average excretion of nitrogen found with the class in physiology in the Harvard Medical School for a number of years past. In the absence of Professor Walter B. Cannon, we must rely upon lecture notes kindly placed at our disposal by Dr. T. M. Carpenter. From analyses of the urinary output of these groups of 40 or more medical students, collected for three successive days, in the years 1909 to 1915, inclusive, the following average values per man per day were obtained: 13.8, 12.0, 12.7, 13.3, 12.7, 12.2, and 12.2 grams of nitrogen excreted. These values are distinctly lower than one would expect when it is considered that the American is commonly believed to live upon the so-called Voit protein standard. The low values found by us with the Y. M. C. A. College students might perhaps be ascribed to the strong tendency at the present time to conserve on meat products, and incidentally on protein foods, the physiological thought in this case being undoubtedly profoundly influenced by the experiments of Professor Chittenden. On the other hand, the fact that the students at the Harvard Medical School have shown these low values since 1909 indicates that the earlier estimates of the American excretion of nitrogen must have been high. The values we find, therefore, are not surprisingly low, and this subsidiary evidence obtained with the medical students confirms our belief that the normal nitrogen excretion of the Y. M. C. A. College undergraduate is not far from 13 to 14 grams. The excessive physical exercise and probably larger amounts of food eaten by the students of the Springfield college, as compared with the students of the Harvard Medical School, would normally account for the slightly higher nitrogen output and protein level at which they were living.

NITROGEN OUTPUT OF SQUAD A AT LOW WEIGHT-LEVEL.

The average nitrogen excretion of Squad A from December 3 to the end of the experiment was 10.5 grams. (See table 73.) This probably represents on the whole the most constant period of lower weight during the experiment, although the second part of this period is complicated by the abnormal rises in weight incident to the Christmas vacation. We may take this nitrogen value, therefore, as an approximate indication of the level of nitrogen upon which these men were capable of living with their lowered intake.

A comparison of the nitrogen excretions in the urine at these different weight-levels is of great significance as indicating the possibility of a material reduction of protein in the diet, protein being one of the most costly food constituents. After the extensive experience of Professor Chittenden, and more particularly the recent compulsory experience of the Central Powers, any real danger from a reduction of protein in the intake seems to be lacking. It was emphasized at the outset that we did not intend to complicate our problem by control of the protein intake. We were not advocating either a high or a low protein diet or a vegetarian or mixed diet. We were confessedly somewhat surprised at the conclusion of the research to find that the nitrogen excretion, especially at the lower weight-level, and with a material reduction in the caloric intake still remained so high, for we had expected it to be somewhat lower. The fact that this did not come to our attention until some time after the experiment ceased shows the complete objectivity of our method of weight reduction and food control. The criterion as to food allotment was, in every instance, the actual weight of the subject. Since the exact knowledge of the intake of nitrogen and energy depends upon chemical analysis and determination of the heat of combustion, the actual ingestion of energy and nitrogen per day could only be computed several weeks later. This in part accounts for the noticeable variations in the intake of energy and nitrogen frequently appearing in the tables.

We have no reason to believe that a somewhat lower protein level might not have readily been obtained without a correspondingly great increase in calories. This, however, remains a disputed point. The fact that nitrogen equilibrium, or at least an indication of nitrogen equilibrium in the frequent appearance of plus values at the lower weight-level, was obtained with the surprisingly low caloric intake of 1,950 calories is, we believe, a new feature. It has been supposed from earlier feeding experiments that no material reduction in the nitrogen excretion can be maintained without very considerably *increasing* rather than *decreasing* the calories. Professor Chittenden, without absolute caloric dietetic control, showed that his soldiers were able to subsist with a low nitrogen output with no great increment in calories. Indeed, his evidence strongly suggested lowered calories. This research fully confirms his inferences with regard to this point.

CLINICAL EXAMINATION.

A preliminary medical examination of all but one of the men in Squad A was made by Dr. Walter H. Chapin, of Springfield, in October, 1917. The results of these examinations are given in the personal histories (see pp. 47 to 53). In addition, arrangements were made with Dr. H. W. Goodall, of Boston, to give the men a complete clinical examination every time they came to Boston for the biweekly experiments in the group respiration chamber. In these examinations of Dr. Goodall particular attention was given to blood pressure. The results of these determinations will be considered in another section. (See p. 370.) Dr. Goodall went over each man with characteristic care, which is particularly exemplified by his method in examining the subject of the long fast in the Nutrition Laboratory.[1] The members of Squad A were first seen by Dr. Goodall on October 13, 1917. His report, aside from blood-pressure observations, for each subject follows:

DETAILS OF CLINICAL EXAMINATION.

Bro.—October 13, 1917, entirely negative, with exception of slightly enlarged tonsils and very small cervical glands. During the period of observation no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, or lungs, percussion outline of heart, or size of liver. Nothing remarkable noted in physical condition of abdominal organs. On February 2, 1918, right kidney felt for first time.

Can.—October 13, 1917, negative, with exception of slightly enlarged tonsils. Slight changes noted in percussion outline of heart area as follows: October 13, left border of cardiac dulness 11 cm. from median line, right, 2.5 cm.; October 27, left border, 11 cm., right border, 2 cm.; November 10, left border, 10 cm., right border 2 cm.; same on all following examinations. No change noted in abdominal organs except that on November 10, right kidney palpable for first time; felt at each subsequent examination.

Fre.—October 13, 1917, negative, except for very small cervical glands. Heart: Left border cardiac dulness 6.5 cm. from median line, right border, 1.5 cm. Seen only once.

Gar.—October 13, 1917, entirely negative, with exception of slightly enlarged tonsils. During period of observation no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, or lungs. Slight changes noted in percussion outline of heart as follows: October 13, left border of cardiac dulness 10 cm., right border 3 cm. from median line; October 27, left border 10 cm., right border 2 cm.; in all subsequent examinations left border, 9 cm., right border, 2 cm. No change noted in abdominal organs, except that on November 10 right kidney was just palpable and at all subsequent examinations.

Gul.—October 13, 1917, entirely negative, except for slightly enlarged tonsils and small cervical glands. During period of observation no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, and lungs. No change noted in percussion outline of heart or abdominal organs. Kidney not felt at any examination.

Mon.—October 13, 1917, entirely negative, with exception of slightly enlarged tonsils and small axillary glands. During period of observation

[1] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 53.

no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, and lungs. A slight change noted in percussion outline of heart: October 13, 1917, left border of cardiac dulness 11 cm. and right border 1.5 cm. from median line; October 27, left border 10.5 cm., right border 2 cm.; November 10, left border 9 cm., right border 2 cm., and the same in subsequent examinations. October 13 and 27, edge of liver felt indistinctly; not felt at any subsequent examination. Right kidney just palpable throughout entire period; otherwise no change in abdominal organs noted.

Moy.—October 13, 1917, entirely negative, except that cervical and axillary glands small. During period of observation no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, and lungs. No change noted in percussion outline of heart or in abdominal organs. Right kidney just palpable on February 2.

Pea.—October 13, 1917, entirely negative, except for slightly enlarged tonsils. During period of observation no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, and lungs. No change in percussion outline of heart or in abdominal organs, except that the liver was just felt with deep inspiration on January 12; subsequent to that date it could not be palpated. Right kidney was palpable for first time on November 10 and in all subsequent examinations.

Pec.—October 13, 1917, entirely negative, except that axillary and epitrochlear glands were small and there was a slight thickening of radial arteries. During period of observation no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, and lungs. No change in percussion outline of heart or in abdominal organs. Kidney not felt.

Spe.—October 13, 1917, entirely negative, except that the tonsils were slightly enlarged and cervical and axillary glands were small. During period of observation no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, and lungs. Heart: Left border of cardiac dulness October 13, 10 cm. from median line, right border 1.5 cm.; October 27, left border 9.5 cm., right border 2 cm.; November 10, left border 8 cm., right border 2 cm., and the same on all following examinations; last examination, December 8. No change noted in abdominal organs. Kidney not palpable.

Tom.—October 13, 1917, entirely negative, except for slightly enlarged tonsils; pharynx reddened and axillary glands small. During period of observation no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, and lungs; no change in percussion outline of heart or abdominal organs. Kidney not palpable.

Vea.—October 13, 1917, entirely negative, except for small cervical glands. During period of observation no change noted in general appearance, skin, mouth, and contained organs, glands, reflexes, chest, and lungs; no change in percussion outline of heart or abdominal organs except that right kidney was just palpable on February 2.

Kon.—October 27, 1917, entirely negative, except for slightly enlarged tonsils. During period of observation no change noted in general appearance, skin, mouth and contained organs, glands, reflexes, chest, and lungs. A faint systolic murmur over the base of the heart heard throughout. Left border of cardiac dulness October 27, 10 cm. from median line, right border 2.5 cm.; November 10 and 24, December 8 and 22, left border 10 cm., right border 2 cm.; January 12, left border 10 cm., right border 1.5 cm.; January 26 and February 2, left border 9 cm., right border 2 cm. No change noted in abdominal organs except that right kidney was palpable after January 12.

The general physical examination of all the men in Squad B was negative. Examinations were made on January 5, 13, 19, and 27, 1918, when all the men were seen. No changes were noted in the percussion of the heart area.

GENERAL OBSERVATIONS.

In view of his extensive experience as a clinician and his practice in medical examinations, Dr. H. W. Goodall's observations and comments on these men as the research continued are significant. These are given in a letter written a few weeks after the close of the research, and reproduced here. In partial explanation of this letter it should be stated that Dr. Goodall said to one of us that he considered these men were in no condition to endure severe muscular exercise as, for example, trench fighting. It was in response to our request for an elaboration of this statement that he made the following comments:

"According to my notes the attention of the men was considerably fixed upon their low diet on the 10th of November. There was no evidence of any particular physical weakness at that time. On the 24th of November it seemed to me that they moved around with considerably less energy, and on the 8th of December they all complained of not feeling specially well. There was a distinct sense of fatigue on muscular exertion, they found it difficult to study, they were thinking of food all the time. After the Christmas holidays, however, they complained very little, and seemed much stronger and better. It was on the 8th of December that I told you I did not believe these men would be fit to do work in the trenches."

ILLNESS.

With a group of 25 college students under observation for 3 to 4 months it would be expected that a certain number of minor illnesses, colds, slight infections, etc., would occur. These appeared in both Squads A and B and apparently as often in Squad B prior to dietetic restriction as in Squad A. In the personal histories, however, emphasis has been laid only upon those slight illnesses which were observed with Squad A. The extraordinary severity of the winter and the necessity for many of the men in Squad A to increase their clothing materially perhaps make it all the more surprising that a larger number of colds and minor illnesses did not occur. The question of constipation, which was present more or less as a result of the reduced and somewhat concentrated diet, was readily controlled in most cases by the use of bran and has been discussed in detail in the section on diets. The only serious trouble was with *Tom*, who stated that he believed the condition which made his operation for hemorrhoids necessary was the result of straining at stools during the reduced diet.

One of our first difficulties experienced with the two squads was the distinct tendency for the men to overeat on the free Sundays permitted once in two weeks. This resulted almost invariably, especially at the

beginning, in digestive disturbances which bordered on nausea and occasionally provoked diarrhea. This tendency to overeat, with consequent digestive disturbance, persisted more or less throughout the entire experiment in spite of repeated warnings.

In a number of instances there appeared to be clear evidence of so-called hunger pains. Certain of the men complained of a continuous gnawing sensation in the stomach, headaches, inability to study, etc. These minor disturbances were anticipated; in fact, the men were told at the beginning that discomfort might be experienced as a result of the restriction in diet. Only one subject found it necessary to withdraw on this account. *Fre*, three weeks after the beginning of the experiment, found himself discommoded by the feeling of hunger and the time demands of the experiment. He became very much disturbed, and, on the advice of the physician, withdrew from the squad. At first his physician suspected the discomfort might be due to a gastric ulcer, and with this possibility it appeared unwise to continue him on the squad. As a matter of fact, when full diet was resumed all his symptoms disappeared.

At least three of our subjects underwent ether narcosis for minor operations during the research. Thus *Bro* injured his foot in a football game and, as shown in his personal history (see p. 47), underwent ether narcosis for a resetting of the toe. He experienced no difficulty and made a rapid, uneventful recovery. *Kon* underwent ether narcosis for a throat and nose operation which involved the removal of adenoids and tonsils, trimming of turbinated bones, and straightening of the septum (see p. 48). *Tom*, in the Christmas vacation, was operated on for hemorrhoids under ether narcosis, but evidently returned to college too soon after the operation. Yet we have no reason to believe that the fact that he was on low diet in any way delayed his ultimate recovery. His post-dietetic history shows that he finished his college work in good condition and, in fact, was one of the best students in the institution.

The post-experimental history of practically all the men in both squads showed pronounced digestive disturbances following the return to normal diet. Special cautions were given to resume normal diet very slowly, but the men not only overate but, in certain instances, passed all reasonable bounds. The reports of the meals eaten by some of the men are so amazing as to seem of doubtful value and hence are not recorded here. Many suffered from abdominal pains and distress, not infrequently nausea, but usually all the men were in good condition within 2 or 3 days.

The most pronounced and puzzling development of abnormal nature throughout the entire test was that occurring with *Spe*. In the experiments in the group chamber apparatus on the morning of December 9 his rectal temperature at 6 a. m. was 97.6° F., and pulse rate 53. On

December 10 and 11 he reported that he felt very well. On December 12 he reported that he felt weak and that his throat was a little sore. His temperature at $5^h\ 45^m$ a. m. was 99.6° F. He was therefore excused from the respiration test and stayed in bed with a headache and a poor appetite. December 13 he reported himself as feeling better, with a temperature of 100.5° F. in the early morning. The temperature, taken at 2 p. m. by a local physician, was reported as 102° F. and the pulse rate as 120. At $6^h\ 30^m$ p. m. the temperature was 102.5° F. and the pulse-rate was 102. The physician and two others suspected typhoid fever and advised him to return home. On December 15, although he still had a high fever, he went to his home at Andover, Massachusetts, and the case was pronounced typhoid fever by his local physician. The subsequent course of the disease is best recorded by the charts of the temperature, pulse, and respiration (figure 87), and by the reports kindly furnished us by the subject's physician, Dr. W. D. Walker, of Andover.

The treatment given *Spe*, as outlined by Dr. Walker, is as follows:

"Warm bath every day; cold sponge for temperature; mouth irrigated with Dobell's solution every 2 hours; swabs of Tr. Myrrh frequently; gargle and spray before and after feedings; drops in the eyes three times a day."

The physician adds that his patient had 24 days of temperature, a very sore mouth for two weeks and a cough. Through Dr. Walker's kindness we are permitted to quote from his letters further as follows:

"Wesley G. Spencer came home from Springfield with a diagnosis of typhoid fever. At the end of nine days he had a crop of what I supposed were rose spots, but their subsequent behaviour leads me to conclude that I was wrong. They were at first rosy red, much larger than the ordinary rose spot and speedily became vesicles. They were all over the body, but more especially on the penis and scrotum, where they caused considerable irritation. All this time the patient's mouth was in a most deplorable state in spite of constant care. A bronchitis was present. The temperature chart you have. There were no abdominal symptoms. A slight trace of albumin was present in the early part of the fever. Widal reactions taken at weekly intervals negative. Urine and stools negative for typhoid bacilli. I conclude that he did not have typhoid, but I cannot make a diagnosis."

Subsequent correspondence with Dr. Walker, with special reference to the character of the vesicles, is as follows:

"The eruption in his case came on the ninth or tenth day, first on the abdomen and arms. It was at first very much like large rose spots, but these in a day or two became vesicular. There was no bleeding. I should say there was no ulceration, except on the scrotum and glans penis, where the eruption was abundant and marked. There was some pigmentation after the vesicles dried up and the spots were still visible after several weeks. The mouth first became involved about the sixth or seventh day of the disease. I am not quite clear as to the progress of this condition, but the whole inner surface of the cheeks and tongue was involved and covered with a dirty greyish membranous coating which finally peeled off after at least a week and possibly longer. There was considerable bleeding from the areas

about the inside of the lips, which were much swollen. I have told you of the bronchitis which accompanied the disease. I had the sputum examined for tuberculosis on two occasions, with negative result. I had no report as to any other organism.

"The eruption was pretty generally distributed over the whole body, arms, legs, back, and, I think, on the forehead. The spots were fairly far apart; for example, perhaps a dozen spots on the abdomen and chest, half a dozen on the arm, etc. These are, of course, only guesses, but the glans penis and scrotum were peculiarly involved and were quite sore."

Simultaneously with the illness of *Spe* the younger brother and the attending nurse became ill. The following sentence in Dr. Walker's letter relates to this phase of the illness:

"The brother's illness came after Wesley's. It began about ten days after Wesley came home and was like a grippe bronchitis with persistent and moderately high fever which lasted ten days to two weeks. No eruption or sore mouth. The nurse who cared for these boys was also ill for a few days with a bronchial attack with fever for a few days. Much milder than the brother's."

Of special note in connection with this case is the fact in the first place that the subject obtained this infection which, it is reasonable to argue, he might not have had if he had been on normal diet. On the other hand, he made complete recovery and returned to college on April 2, 1918. He has completed his college year and is in excellent health. It is extremely unfortunate that a clear, unquestioned diagnosis could not have been made of this case. Conference with several of the best clinicians in Boston leaves the whole situation very uncertain. It would be useless here to record the various conjectures made from the clinical picture outlined, but there seems to be a reasonable uniformity of opinion that *Spe* did not have typhoid fever.

The whole history of this case is of special interest, in connection with the statement made by Loewy and Zuntz in the article reporting their experience on war diet, in which they especially emphasize the fact that the possibility of a lowered resistance to infectious diseases can only be studied when there is extensive clinical material at hand.

The number of men under observation was approximately 25. One (*Fre*) withdrew primarily on account of his inability to withstand the discomfort of hunger pains. *Spe* is the only case of a serious illness occurring during the research. Since all the men were given substantially the same treatment, ate at the same table, and had the same food, it is highly probable that we deal in this case with a sporadic infection that is without direct connection with the dietetic conditions. It still remains a fact, however, that one man out of the 25 men studied—*i. e.*, 4 per cent of our men—contracted a severe illness. This, in connection with the suggestion made by Dr. Minot in his report on the blood examination, would certainly be taken into account as an argument against the general use of restricted diets.

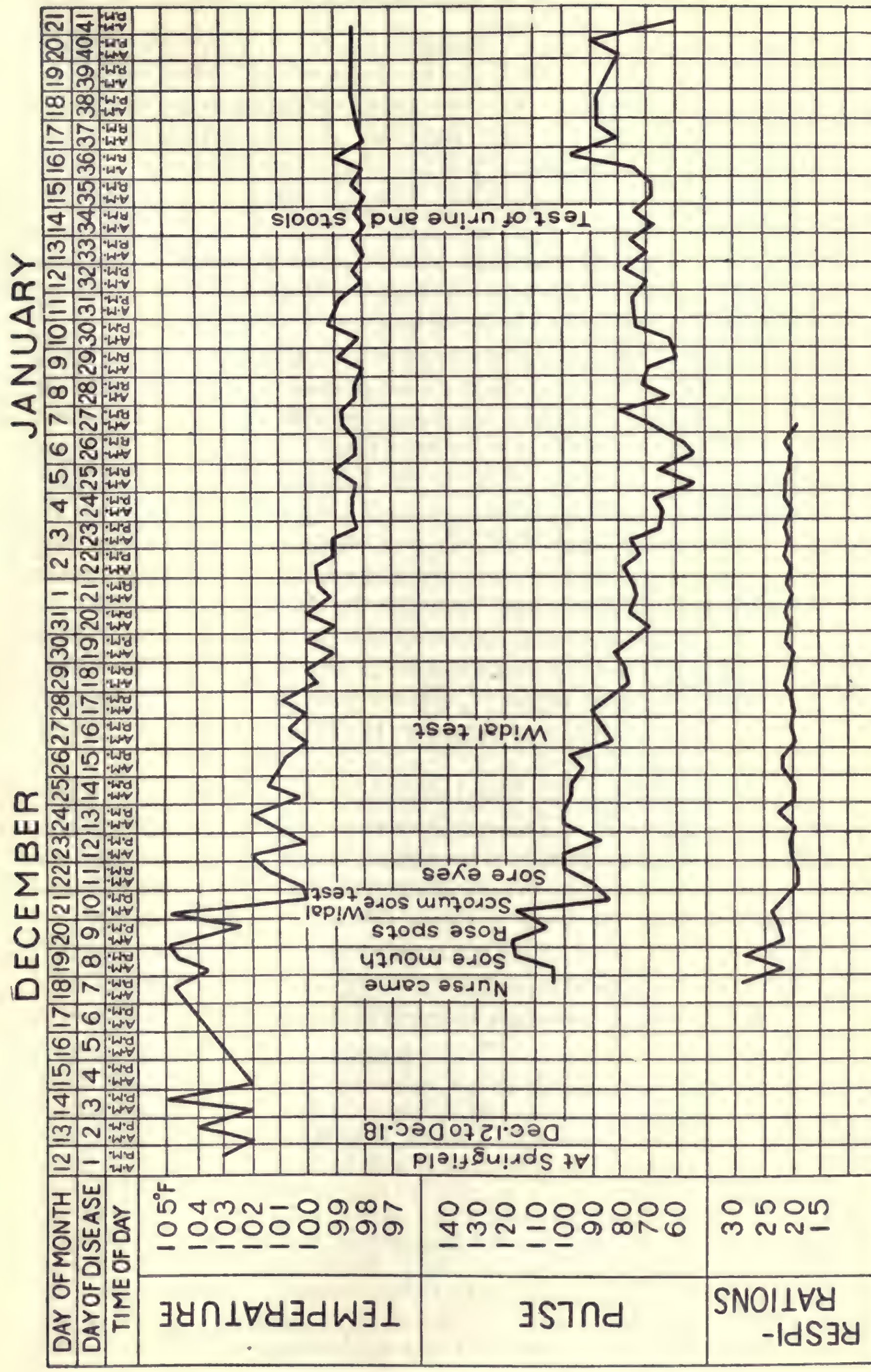

FIG. 87.—Temperature, pulse, and respiration charts of Wesley G. Spencer (*Spe*) during suspected infection of typhoid fever, December 12, 1917—January 21, 1918.

BLOOD EXAMINATION.

Although the morphological changes in blood observed for the fasting man previously studied in this Laboratory[1] were relatively slight, it seemed desirable to secure certain evidence as to the blood with the subjects of the low-diet research, so as to contribute in every way possible to the general picture of the influence of a reduced diet. Accordingly, through the kind offices of Dr. George R. Minot, the services were enlisted of Miss Anna L. Gibson and Miss Myra B. Conover, the expert technicians of the Collis P. Huntington Memorial Hospital. Blood counts were made on both squads when they came to Boston for the biweekly experiments.

Additional information regarding the possible effect of the diet upon the blood is given by the fact that at no period throughout the test did the subjects appear to the examining physician as at all anemic. He saw them, however, only under artificial light. Dr. J. H. Kellogg, of the Battle Creek Sanitarium, when at the Laboratory on the last day of the research, thought the men appeared anemic. Professor G. B. Affleck, of the International Y. M. C. A. College, who was one of the coaches and instructors and saw the men in gymnasium suits and under the best daylight conditions, also thought the men looked anemic.

As was noted in the personal histories (see p. 49), one of the subjects, *Gul*, donated blood for transfusions at the Springfield Hospital, the amounts being on December 23, 100 c.c.; on December 29, 50 c.c.; on January 6, 90 c.c.; and on January 17, 50 c.c., making a total amount of 290 c.c.

The data obtained from the blood examinations in this research are given in tables 74 and 75. These values may be compared with the statement of Loewy and Zuntz, who report "as a good sign" that in their study on themselves the determinations made by the Plesch hemoglobinometer showed for both of them 110 per cent hemoglobin.

For the interpretation of the large number of blood counts made by Miss Gibson and Miss Conover, we are very much indebted to Dr. Minot, who has been good enough to contribute the appended report:

BOSTON, MASS., *June 18, 1918.*

The data on the blood examinations made by Miss Gibson and Miss Conover, both expert technicians and nurses of the Collis P. Huntington Memorial Hospital, show in general, I think, that both Squads A and B developed during the course of the experiment a definite, though slight to mild, secondary anemia. In general, it is evident that both the hemoglobin and red count are reduced, and the color index tends to be lower than normal. (Eighty-five per cent or above for the hemoglobin is normal with the Sahli instrument used.) These findings are very slight in some instances, and quite marked in others, and more evident with Squad A than Squad B. In certain instances it may be noted that instead of a progressively falling red count, there occurs a slightly increased count following a previously lower

[1] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 148.

count. This may be dependent upon a temporary concentration of the blood, or dependent perhaps upon an actual increase of cells which are relatively poor in hemoglobin, as told by their histological character and the fact that the hemoglobin did not significantly rise with the increased count. The relatively slight histological abnormalities noted about the red cells, the achromia, anisocytosis, occasionally polychromatophilia, are those associated with slight or mild secondary anemia.

The white counts, in general, average 9,500, but little higher than normal (normal average, 7,300). With Squad B, who had not been so long on reduced diet, the white counts showed no alteration. The evidence is therefore negative so far as the white counts alone are concerned.

The white cells are evidently of the normal types, but their normal proportion is disturbed. This is evidenced by the fact that the average per cent (36) and the average absolute number (3,400) of the lymphocytes are unusually high for individuals in this vicinity, the average normal lymphocyte count being 22 per cent (though the upper normal limit may be 40 per cent) and the average normal absolute count being 1,724.[1] In Squad B, in certainly 8 out of 12 cases, the lymphocytes definitely increased, both relatively and absolutely, under observation, while, though variations occur in Squad A, the average lymphocyte count is certainly well above the normal average. This increase is perhaps at the expense of polynuclear neutrophile production, for the polynuclear per cent, both squads, averages 56 per cent, which is slightly lower than the normal average, 64 per cent. However, the average absolute number of polynuclears is not so significantly altered from their normal average (4,895) as are the lymphocytes. This increase of lymphocytes is not an unusual finding in chronic secondary anemia.

The other white cells show no definite significant alteration, though in some instances the eosinophiles are very slightly more numerous than normal. Satisfactory data concerning the blood platelets, the third formed element of the blood, originating from myelogenous tissue, are unfortunately lacking. One usually finds them increased in secondary anemia, although when associated with decreased blood formation, they may become decreased.

The secondary anemia present in these cases may be dependent, perhaps, in some manner upon a decreased rate of blood formation, possibly similar to that which occurs in myxedema.

It is interesting to speculate as to what might happen to the blood of these individuals if they were kept on this same diet for a considerably longer period of time. I am inclined to believe that, under such circumstances, a greater degree of secondary anemia than the most marked case shows would probably not occur, or that it would be but very slightly greater. In other words, it seems to me that their blood would stay at a new level, one which we would interpret as a mild secondary anemia. However, I think that, if for any considerable time the blood remained at this new level, it would probably be quite difficult, perhaps impossible, for it to return to its previous normal level, and that if it did return to normal, it would probably do so very slowly. This is because, from clinical experience, the blood of cases of chronic mild secondary anemia, dependent upon various minor causes, not infrequently improves only slightly following prolonged appropriate treatment. It would seem in some such instances as if some "trap had been sprung" which could not be entirely repaired to let the completely normal hemopoetic function take place again. This may be well seen in certain rather marked and unusual cases of anemia dependent upon chronic benzol poisoning—a drug which causes an aplastic type of anemia.

George R. Minot, M. D.

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[1] S. R. Miller, Johns Hopkins Hospital Bulletin, 1914, **25**, p. 317.

TABLE 74.—*Results of blood examinations during period of reduced diet—Squad A.*

Subject and date.	Time.	Hemoglobin. (Sahli).	Total erythrocytes.	Total leucocytes.	Differential counts. Polymorphonuclear neutrophiles. Total.	Polymorphonuclear neutrophiles. Per cent.	Lymphocytes. Total.	Lymphocytes. Per cent.	Mononuclears. Total.	Mononuclears. Per cent.	Eosinophiles. Total.	Eosinophiles. Per cent.	Remarks on erythrocytes.
BRO.	*p. m.*	*p. ct.*	*millions.*										
Dec. 19, 1917...	8.20	80	4.568	8,400	5,124	61	2,520	30	756	9	......	......	Slight achromia and anisocytosis.
Jan. 12, 1918...	8.35	80	3.420	10,400	6,240	60	3,328	32	728	7	104	1	Do.
Jan. 26, 1918...	9.20	76	3.880	12,000	6,480	54	5,040	42	480	4	......	......	Considerable achromia and slight anisocytosis.
Feb. 918...	7.40	78	3.840	8,000	4,160	52	3,200	40	560	7	80	1	Slight achromia and anisocytosis.
CAN.													
Dec. 19, 1917...	7.20	80	3.856	14,000	9,800	70	2,940	21	980	7	280	2	Slight achromia and anisocytosis.
Jan. 12, 1918[1]..	9.25	72	3.200	12,000	7,560	63	3,600	30	720	6	......	......	Do.
Jan. 26, 1918[2]..	7.45	78	3.688	7,000	3,780	54	2,380	34	630	9	140	2	Marked achromia and slight anisocytosis.
Feb. 2, 1918...	7.20	72	5.080	12,800	7,424	58	4,608	36	768	6	......	......	Slight achromia.
KON.													
Dec. 19, 1917...	8.30	76	5.368	6,000	3,300	55	2,400	40	180	3	120	2	Considerable achromia and anisocytosis.
Jan. 12, 1918...	7.15	74	4.280	9,000	5,850	65	2,610	29	540	6	......	......	Do.
Jan. 26, 1918...	8.15	78	4.480	9,200	5,980	65	2,760	30	368	4	92	1	Slight achromia.
Feb. 2, 1918...	8.00	78	4.832	9,600	6,144	64	2,688	28	576	6	192	2	Do.
GAR.													
Dec. 19, 1917...	8.50	80	5.976	16,000	7,200	45	6,560	41	1,280	8	960	6	Slight achromia, polychromatophilia and anisocytosis.
Jan. 12, 1918...	8.35	70	4.621	9,600	4,128	43	4,512	47	576	6	384	4	Slight achromia and anisocytosis.
Jan. 26, 1918...	8.55	73	4.328	10,000	5,400	54	4,000	40	500	5	100	1	Do.
Feb. 2, 1918...	8.20	70	4.132	7,200	4,320	60	2,592	36	288	4	......	......	Do.
GUL.													
Dec. 19, 1917[3]..	7.20	74	5.728	10,800	5,508	51	3,780	35	1,080	10	324	3	Slight anisocytosis.
Jan. 12, 1918...	9.05	76	4.480	10,800	5,940	55	3,888	36	432	4	540	5	Considerable achromia.
Jan. 26, 1918...	9.05	78	4.288	8,600	4,902	57	2,580	30	688	8	430	5	Slight anisocytosis.
Feb. 2, 1918...	8.20	75	4.160	8,000	3,840	48	3,680	46	480	6	......	......	Slight achromia and anisocytosis.

MON.													
Dec. 19, 1917...	9.10	75	4.240	9,000	4,950	55	3,150	35	630	7	270	3	Considerable achromia and anisocytosis.
Jan. 12, 1918...	8.05	70	4.416	11,200	4,928	44	5,488	49	448	4	336	3	Do.
Jan. 26, 1918...	8.35	80	4.536	8,800	4,752	54	3,520	40	528	6	....	.....	Normal.
Feb. 2, 1918...	7.40	76	4.132	8,000	4,960	62	2,800	35	240	3	....	.....	Slight achromia.
MOY.													
Dec. 19, 1917...	8.10	80	5.040	12,800	6,912	54	4,224	33	1,280	10	384	3	Considerable achromia and anisocytosis.
Jan. 12, 1918...	7.40	80	4.924	8,800	5,544	63	2,640	30	352	4	264	3	Normal.
Jan. 26, 1918...	7.25	81	4.400	8,200	4,428	54	3,116	38	328	4	328	4	Do.
Feb. 2, 1918...	7.00	80	4.960	12,000	6,240	52	4,560	38	720	6	480	4	Do.
PEA.													
Dec. 19, 1917...	9.00	72	4.880	10,600	5,300	50	4,134	39	742	7	424	4	Considerable achromia and anisocytosis.
Jan. 12, 1918...	8.05	72	3.840	9,600	4,800	50	3,840	40	576	6	384	4	Do.
Jan. 26, 1918...	7.25	78	4.280	8,000	4,000	50	3,280	41	480	6	240	3	Slight achromia and anisocytosis.
Feb. 2, 1918...	8.00	75	3.680	8,000	4,480	56	2,880	36	320	4	320	4	Do.
PEC.													
Dec. 19, 1917...	7.50	88	6.840	9,000	4,770	53	3,150	35	900	10	180	2	Slight anisocytosis.
Jan. 12, 1918...	7.15	86	4.456	5,400	2,592	48	2,484	46	324	6	....	.....	Normal.
Jan. 26, 1918...	9.40	78	4.664	8,000	4,000	50	3,600	45	400	5	....	.....	Do.
Feb. 2, 1918...	7.20	76	4.000	8,200	5,576	68	2,132	26	410	5	82	1	Slight achromia.
TOM.													
Dec. 19, 1917...	8.00	70	4.400	8,000	4,400	55	2,560	32	560	7	480	6	Considerable achromia and anisocytosis.
Jan. 12, 1918...	9.05	66	5.120	8,800	4,840	55	3,432	39	264	3	264	3	Do.
Jan. 26, 1918...	9.36	78	5.160	12,800	7,168	56	4,608	36	768	6	256	2	Normal.
Feb. 2, 1918...	7.00	80	4.508	12,800	7,488	59	4,512	35	544	4	256	2	Do.
VEA.													
Dec. 19, 1917...	8.40	92	4.408	7,000	3,920	56	2,170	31	420	6	490	7	Slight achromia.
Jan. 12, 1918...	7.40	60	4.496	6,600	3,300	50	2,640	40	462	7	198	3	Slight achromia and anisocytosis.
Jan. 26, 1918...	8.15	64	4.608	7,200	4,104	57	2,376	33	576	8	144	2	Considerable achromia and anisocytosis.
Feb. 2, 1918...	8.35	70	4.000	8,000	4,240	53	3,040	38	480	6	240	3	Considerable achromia and slight anisocytosis.
Average..	......	76	4.504	9,460	5,245	55	3,409	36	576	6	222	2.3	

[1] Mast cells, 120 or 1 per cent. [2] Mast cells, 70 or 1 per cent. [3] Mast cells, 108 or 1 per cent.

TABLE 75.—*Results of blood examinations—Squad B.*

Subject and date.	Time.	Hemoglobin. (Sahli).	Total erythrocytes.	Total leucocytes.	Differential counts. Polymorphonuclear neutrophiles. Total.	Polymorphonuclear neutrophiles. Per cent.	Lymphocytes. Total.	Lymphocytes. Per cent.	Mononuclears. Total.	Mononuclears. Per cent.	Eosinophiles. Total.	Eosinophiles. Per cent.	Remarks on erythrocytes.
FIS.	*p. m.*	*p. ct.*	*millions.*										
Jan. 5, 1918[1]	7.45	86	5.754	8,000	4,000	50	2,720	34	800	10	320	4	Normal.
Jan. 13, 1918[2]	6.50	85	4.842	12,800	8,192	64	3,968	31	384	3	128	1	Do.
Jan. 19, 1918	7.40	85	5.216	10,400	5,200	50	4,680	45	520	5	......	.....	Do.
Jan. 27, 1918	7.15	87	5.336	5,600	2,800	50	2,240	40	504	9	56	1	Do.
HAR.													
Jan. 5, 1918[3]	8.00	80	4.200	9,600	5,856	61	2,640	27.5	960	10	48	0.5	Normal.
Jan. 13, 1918	7.40	80	4.401	9,600	4,896	51	3,840	40	192	2	672	7	Do.
Jan. 19, 1918	7.40	78	3.520	9,200	4,876	53	3,680	40	276	3	368	4	Slight achromia.
Jan. 27, 1918	7.55	82	3.360	10,000	6,000	60	3,500	35	400	4	100	1	Do.
HOW.													
Jan. 5, 1918	8.40	95	5.160	8,000	4,800	60	2,400	30	720	9	80	1	Normal.
Jan. 13, 1918	7.40	85	4.120	6,000	3,840	64	1,860	31	240	4	60	1	Slight anisocytosis.
Jan. 19, 1918	8.20	72	4.288	8,000	4,480	56	3,200	40	320	4	......	.....	Slight anisocytosis and achromia.
Jan. 27, 1918	8.40	85	4.320	8,800	4,224	48	3,960	45	616	7	......	.....	Normal.
HAM.													
Jan. 5, 1918	8.24	90	4.576	8,000	4,960	62	2,240	28	560	7	240	3	Normal.
Jan. 13, 1918	6.50	90	4.680	8,200	5,084	62	2,460	30	492	6	164	2	Do.
Jan. 19, 1918	6.50	78	4.512	8,800	4,752	54	3,520	40	264	3	264	3	Slight achmroia.
Jan. 27, 1918	7.35	87	5.496	7,600	3,420	45	3,268	43	608	8	304	4	Normal.
KIM.													
Jan 5, 1918	9.15	82	5.584	8,000	4,400	55	3,200	40	320	4	80	1	Normal.
Jan. 13, 1918	8.40	84	4.672	8,800	4,136	47	3,784	43	704	8	176	2	Do.
Jan. 19, 1918	8.35	80	4.032	12,800	6,400	50	5,632	44	768	6	......	.....	Do.
Jan. 27, 1918	9.20	75	4.192	6,000	3,000	50	2,700	45	240	4	60	1	Considerable achromia and anisocytosis.
LON.													
Jan. 13, 1918	8.05	80	4.000	10,600	7,844	74	2,120	20	424	4	212	2	Slight achromia.
Jan. 19, 1918	6.50	84	3.200	8,000	5,120	64	2,400	30	320	4	160	2	Do.
Jan. 27, 1918	8.20	72	5.440	8,000	4,000	50	3,600	45	400	5	......	.....	Slight achromia and anisocytosis.

SCH.													
Jan. 5, 1918...	9.40	91	6.016	8,800	6,160	70	2,464	28	176	2	......	.....	Normal.
Jan. 13, 1918...	8.20	80	4.800	8,000	5,440	68	2,080	26	320	4	160	2	Do.
Jan. 19, 1918...	7.15	79	3.392	6,600	4,092	62	2,112	32	264	4	132	2	Slight achromia.
Jan. 27, 1918...	8.40	80	3.760	6,000	3,600	60	2,100	35	300	5	......	.....	Slight achromia and anisocytosis.
LIV.													
Jan. 5, 1918...	7.45	85	6.400	10,000	7,000	70	2,400	24	600	6	......	.....	Normal.
Jan. 13, 1918...	8.20	82	5.666	9,600	6,144	64	2,688	28	576	6	192	2	Do.
Jan. 19, 1918...	8.20	80	4.592	11,200	6,720	60	3,360	30	672	6	448	4	Do.
Jan. 27, 1918...	......	82	4.000	9,000	5,220	58	3,330	37	450	5	......	.....	Do.
SNE.													
Jan. 5, 1918...	9.40	79	6.656	8,000	5,040	63	2,400	30	480	6	80	1	Normal.
Jan. 13, 1918...	8.40	78	4.772	8,800	5,104	58	3,344	38	352	4	......	.....	Slight achromia.
Jan. 19, 1918...	8.00	75	4.608	10,400	6,448	62	3,536	34	208	2	208	2	Slight achromia and anisocytosis.
Jan. 27, 1918...	7.55	75	4.280	5,200	3,016	58	1,768	34	312	6	104	2	Considerable achromia.
THO.													
Jan. 5, 1918[4]...	9.15	92	5.892	10,000	6,600	66	2,200	22	1,000	10	100	1	Normal.
Jan. 13, 1918...	7.15	90	4.400	8,000	4,480	56	2,720	34	640	8	160	2	Do.
Jan. 19, 1918...	8.00	85	4.320	10,000	6,000	60	3,600	36	200	2	200	2	Do.
Jan. 27, 1918...	8.20	87	5.056	8,000	4,560	57	3,120	39	320	4	......	.....	Do.
VAN.													
Jan. 5, 1918...	8.24	88	5.480	9,000	5,670	63	2,610	29	540	6	180	2	Normal.
Jan. 13, 1918...	8.05	85	4.920	8,800	5,016	57	3,168	36	352	4	264	3	Do.
Jan. 19, 1918...	9.00	80	4.056	7,200	4,320	60	2,160	30	576	8	144	2	Do.
Jan. 27, 1918...	7.35	76	4.800	8,000	4,800	60	2,720	34	320	4	160	2	Slight achromia and anisocytosis.
WIL.													
Jan. 5, 1918...	8.40	86	5.000	12,800	7,168	56	4,480	35	768	6	384	3	Normal.
Jan. 13, 1918...	7.15	70	4.128	8,800	5,192	59	2,904	33	440	5	264	3	Considerable achromia and anisocytosis.
Jan. 19, 1918...	7.15	73	4.160	10,400	6,136	59	3,328	32	780	7.5	156	1.5	Slight achromia and anisocytosis.
Jan. 27, 1918...	9.00	80	4.720	6,400	3,712	58	2,304	36	384	6	......	.....	Normal.
AVERAGES:													
Normal diet—													
Jan. 5, 1918....	......	87	5.520	9,100	5,605	61	2,705	30	629	7	137	1.5	
Reduced diet—													
Jan. 13–27, 1918.	......	81	4.446	8,600	4,952	57	3,077	36	421	5	148	1.7	

[1] Mast cells, 160 or 2 per cent. [2] Mast cells, 128 or 1 per cent. [3] Mast cells, 96 or 1 per cent. [4] Mast cells, 100 or 1 per cent.

BLOOD PRESSURE.

As the blood pressure is an important factor such determinations were made a part of the regular clinical examinations by Dr. H. W. Goodall when the men came to Boston for the experiments in the group respiration chamber. Standard technique was used, namely, the apparatus of the Taylor Instrument Company (Tycos) and the auscultatory method for both systolic and diastolic pressures. The particular instrument employed had the usual Bourdon gage. This was frequently compared with a mercury manometer to insure the accuracy of the blood-pressure records. The blood pressures recorded by Dr. Goodall were always taken with the subject in the sitting position and with the cuff on the left arm. These determinations were almost invariably made between 8 and 10 p. m., before the subjects entered the respiration chamber.

In the latter part of the research, a series of blood-pressure tests was made with a second instrument by one of us and by the skilled superintendent of the Huntington Memorial Hospital, Miss Anna L. Gibson. This instrument (a duplicate of the one used by Dr. Goodall) was likewise compared with a mercury manometer and its accuracy established. We have every confidence, therefore, in the two instruments used. Special emphasis is laid upon this fact, for the astounding changes in blood pressure render the technique liable to special scrutiny.

The second series of blood-pressure observations included a considerable number of blood pressures which were taken prior to the walking experiments. Successive observations were also recorded immediately after the cessation of walking. The subject was always in the standing position during these determinations, for the first few records, but additional records were made with the subject sitting, usually from 5 to 9 minutes after the walking had ceased. The series of observations after walking provided data for studying the influence of a moderate amount of physical work upon the blood pressure, both systolic and diastolic, and likewise upon the pulse pressure. Such records were deemed significant inasmuch as Cotton, Rapport, and Lewis[1] found a pronounced influence upon blood pressure with strenuous muscular work, even when continued only a short time.

Of special interest in this study is the course of the systolic and diastolic blood pressures and the pulse pressure as the investigation progressed. Unfortunately, we were not able to obtain records of blood pressure for Squad A prior to dietetic restriction. The need of such data is specially brought out in examining the blood pressures of the 12 members of Squad B. With Squad A the blood pressure was

[1] Cotton, Rapport, and Lewis, Heart, 1917, 6, p. 269.

measured first on October 13; the subjects had therefore been upon a reduced diet for 9 days prior to the first measurement.

SYSTOLIC AND DIASTOLIC BLOOD PRESSURE, SQUAD A.

The records of the systolic and diastolic pressures and pulse pressure obtained between October 13 and February 2, inclusive, for Squad A are given in table 76. A glance at this table shows instantly that the blood pressure, both systolic and diastolic, greatly decreased as

TABLE 76.—*Blood-pressure measurements during period of reduced diet—Squad A.*

Date and measurement.[1]	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av. for squad.
Oct. 13, 1917:[2]	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Systolic.......	115	118	.....	115	118	115	120	100	115	116	120	118	115
Diastolic......	90	100	.....	75	75	80	70	70	85	88	80	80	81
Pulse pressure..	25	18	.....	40	43	35	50	30	30	28	40	38	34
Oct. 27, 1917:													
Systolic.......	104	100	140	100	100	100	102	90	105	104	95	100	[3]103
Diastolic......	80	70	90	78	70	82	68	65	75	70	75	60	[3]74
Pulse pressure..	24	30	50	22	30	18	34	25	30	34	20	40	[3]30
Nov. 10, 1917:													
Systolic.......	105	90	110	90	90	90	110	90	85	105	90	95	96
Diastolic......	80	70	90	75	65	80	75	65	75	70	70	65	73
Pulse pressure..	25	20	20	15	25	10	35	25	10	35	20	30	23
Nov. 24, 1917:													
Systolic.......	90	100	100	90	90	90	90	90	90	100	80	90	92
Diastolic......	75	65	65	70	55	70	85	65	75	80	65	65	70
Pulse pressure..	15	35	35	20	35	20	5	25	15	20	15	25	22
Dec. 8, 1917:													
Systolic.......	90	90	90	90	90	90	90	90	90	90	80	90	89
Diastolic......	75	65	85	70	60	65	85	65	75	75	65	65	71
Pulse pressure..	15	25	5	20	30	25	5	25	15	15	15	25	18
Dec. 19, 1917:													
Systolic.......	90	90	90	90	90	90	90	90	90	.....	80	90	89
Diastolic......	75	70	85	70	60	65	85	65	75	.....	65	65	71
Pulse pressure..	15	20	5	20	30	25	5	25	15	.....	15	25	18
Jan. 12, 1918:													
Systolic.......	90	100	110	95	90	90	110	90	100	.....	100	100	98
Diastolic......	75	85	90	80	60	65	70	65	85	.....	70	60	73
Pulse pressure..	15	15	20	15	30	25	40	25	15	.....	30	40	25
Jan. 26, 1918:													
Systolic.......	90	110	95	85	80	90	100	90	90	.....	95	93	93
Diastolic......	75	70	65	60	55	65	60	60	64	.....	65	50	63
Pulse pressure..	15	40	30	25	25	25	40	30	26	.....	30	43	30
Feb. 2, 1918:													
Systolic.......	90	100	95	100	90	95	100	90	90	.....	95	100	95
Diastolic......	65	70	65	65	55	70	60	60	70	.....	65	60	64
Pulse pressure..	25	30	30	35	35	25	40	30	20	.....	30	40	31

[1] All blood-pressure measurements were taken with the Tycos sphygmomanometer with the subject sitting.

[2] Blood-pressure measurements were obtained with *Fre* on Oct. 13, as follows: Systolic, 110; diastolic, 80; pulse pressure, 30.

[3] The averages for Oct. 27, omitting *Kon's* values, are as follows: Systolic, 100; diastolic, 72; pulse pressure, 28.

the diet period continued. The highest values for the systolic pressure were always found in the initial observation. In the majority of instances the highest values for diastolic pressure were likewise obtained at that time but some of the later records show a slight rise. The highest systolic pressure recorded, 140 mm., is that for *Kon* on October 27, 1917. It will be recalled that this subject had not then been subjected to a restriction in the diet, and hence this value represents for him a normal, unaffected blood pressure. A very striking fall in his blood pressure took place in the 2 weeks between the records of October 27 and November 10; that is, the systolic blood pressure fell from 140 mm. to 110 mm.

Considering first the systolic pressures, the difference between the initial record and the absolute minimum found during the experiment is as follows: *Bro*, 25 mm.; *Can*, 28 mm.; *Kon*, 50 mm.; *Gar*, 30 mm.; *Gul*, 38 mm.; *Mon*, 25 mm.; *Moy*, 30 mm.; *Pea*, 10 mm.; *Pec*, 30 mm.; *Spe*, 26 mm. (last observation December 8); *Tom*, 40 mm.; and *Vea*, 28 mm. If one uses the record at the end of the observations, these differences become somewhat smaller with all but *Bro*, *Pea*, and *Spe*. In other words, we note, roughly speaking, an average fall of 20 mm. systolic blood pressure from October 13 until the end of the experiment. We have every reason to believe that the blood pressure fell perceptibly in the 9 days between the beginning of the reduction in diet and October 13, so this 20 mm. represents a distinctly minimum value.

The average systolic pressures for all of the men are given in the last column of table 76. The irregularity in number of subjects, *i. e.*, 11 on the first and the last four dates, and 12 on the other dates, affects the averages but little. The high values for *Kon* on October 27 raise the averages for the three pressures about 3 mm.; the averages for that date without *Kon* are therefore given in a footnote. The maximum average systolic blood pressure is 115 mm. on October 13, while the minimum average is recorded for both December 8 and 19, *i. e.*, 89 mm., this being a total average fall of 26 mm.

The diastolic pressure likewise decreased profoundly, the initial and minimum values being as follows: *Bro*, 90 and 65 mm.; *Can*, 100 and 65 mm.; *Kon*, 90 and 65 mm.; *Gar*, 75 and 60 mm.; *Gul*, 75 and 55 mm.; *Mon*, 80 and 65 mm.; *Moy*, 70 and 60 mm.; *Pea*, 70 and 60 mm.; *Pec*, 85 and 64 mm.; *Spe*, 88 and 70 mm.; *Tom*, 80 and 65 mm.; *Vea*, 80 and 50 mm. In other words, diastolic blood pressures as low as 60 mm. appear with 5 of our subjects; all of the subjects except *Spe* show at some time during the experiment diastolic blood pressures of 65 mm. or less.

The average diastolic pressures, which are also subject to the slight irregularities of averaging noted for the systolic pressures, show a

maximum of 81 mm. on October 13 and a minimum of 63 mm. on January 26, a total fall of 18 mm. It is important to note that the average values for 11 men on January 26 and February 2 are 63 and 64 mm., respectively.

SYSTOLIC AND DIASTOLIC BLOOD PRESSURE, SQUAD B.

Since we have no basal data for the men in Squad A, *i. e.*, measurements prior to dietetic restriction, the values found for Squad B have a special interest, as observations were made with these men the night preceding the beginning of their dietetic restriction (January 5, 1918). The data obtained for Squad B on January 5 and on the subsequent

TABLE 77.—*Blood-pressure measurements—Squad B.*

Date and measurement.[1]	Fis.	Har.	How.	Ham.	Kim.	Lon.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av. for squad.
Normal diet.													
Jan. 5, 1918:[2]	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Systolic	120	138	120	110	105	.....	142	120	120	105	130	105	120
Diastolic	90	80	80	80	80	.....	90	80	80	75	90	85	83
Pulse pressure	30	58	40	30	25	.....	52	40	40	30	40	20	37
Reduced diet.													
Jan. 13, 1918:													
Systolic	105	115	90	90	120	100	120	90	110	90	105	90	102
Diastolic	80	65	60	60	75	65	78	65	70	75	70	65	69
Pulse pressure	25	50	30	30	45	35	42	25	40	15	35	25	33
Jan. 19, 1918:													
Systolic	105	105	100	100	85	90	100	90	110	90	95	90	97
Diastolic	80	60	65	65	60	65	65	60	70	75	65	65	66
Pulse pressure	25	45	35	35	25	25	35	30	40	15	30	25	30
Jan. 27, 1918:													
Systolic	90	100	100	90	85	90	100	85	110	80	100	100	94
Diastolic	70	60	65	55	60	65	65	55	70	65	70	70	64
Pulse pressure	20	40	35	35	25	25	35	30	40	15	30	30	30

[1] All blood-pressure measurements were taken with the Tycos sphygmomanometer, with the subject sitting.

[2] Blood-pressure measurements were obtained with *McM* on Jan. 5, as follows: Systolic, 110; diastolic, 75; pulse pressure, 35.

nights, January 13, 19, and 27, 1918, are given in table 77. The normal values for systolic pressure obtained on January 5 ranged from 105 mm. with *Kim, Tho,* and *Wil,* to a maximum of 142 mm. with *Sch.* The average systolic pressure for the 11 men was 120 mm. The diastolic pressure for this date ranged from 75 mm. with *Tho,* to 90 mm. with *Fis, Sch,* and *Van.* The average diastolic pressure for the 11 men on this day was 83 mm.

One week later (January 13) the systolic pressure had fallen in every case, with the single exception of *Kim,* with whom there was an in-

crease of 15 mm. As a rule, the fall in systolic pressure was not far from 15 to 20 mm., the average systolic pressure for this date being 102 mm. Thus the contention is correct that the systolic pressure noted with Squad A on October 13, one week after the low diet began, represented a distinctly lower level than would have been found had these men been measured prior to the dietetic reduction. It is quite probable, therefore, that an addition of from 10 to 20 mm. to the average systolic blood pressure of October 13 with Squad A should be made to indicate the probable blood pressure of these men prior to dietetic reduction, although the total calories in the diet were much less proportionately with Squad B than with Squad A, and undoubtedly the drafts upon body-material were considerably greater for Squad B during this week. Nevertheless, there must have been a noticeable fall in systolic pressure with Squad A in the week which preceded October 13.

In the two weeks following January 13 there was with Squad B a distinct tendency for the systolic pressures to fall still lower. With *Fis* and *Har*, this fall was 15 mm.; with *How* a slight rise took place; with *Ham* the pressure rose, then fell again; with *Kim* the pressure fell in the later measurements from 120 to 85 mm., a fall of 35 mm. *Lon*, who was not included in the first measurements and hence was measured for the first time after a week's restriction in diet, showed essentially constant blood pressures for the rest of the experiment. With *Sch* a drop of 20 mm. occurred, with *Liv* but 5 mm., with *Sne* there was no further change, with *Tho* there was a drop of 10 mm., with *Van* the fall varied from 10 to 5 mm., and with *Wil* there was a tendency to a slight rise.

The average values given in the last column of table 77 are again open to criticism owing to the absence of *Lon* on January 5, 1918. The minimum average value is 94 mm. on January 27, with a total fall from normal of 26 mm. This minimum of 94 mm. compares with the 95 mm. found as an average value with Squad A on February 2, but is somewhat higher than the actual minimum of 89 mm. found on two nights (December 8 and 19) with Squad A.

Profound alterations in the diastolic pressure likewise appear, even in so short a period of undernutrition as three weeks. Comparing the records for the beginning and end of the observations we find that the diastolic pressure fell from normal with *Ham*, *Sch*, and *Liv*, 25 mm., with *Fis*, *Har*, *Kim*, and *Van*, 20 mm., with *Wil* and *How*, 15 mm., with *Sne* and *Tho*, 10 mm. Diastolic pressures of 65 mm. or below are noted with all of the subjects but *Fis* and *Sne*. The absolute lowest value was 55 mm. which was found with *Ham* and *Liv* on January 27.

The average diastolic pressure for 11 men prior to the restricted diet was 83 mm. on January 5, 1918, and the lowest average diastolic pressure was 64 mm., this occurring on the last day. This average

value of 64 mm. is exactly that noted with Squad A. It is of special interest that one week of a reduced diet, containing only 1,400 net calories, lowered the systolic pressure of 11 men from 120 to 102 mm. and the diastolic pressure from 83 to 69 mm.

PULSE PRESSURE, SQUADS A AND B.

The average normal pulse pressure (*i. e.*, the difference between systolic and diastolic pressures) of college students of this age and environment is shown in table 77 by the values found on January 5 with Squad B, namely, 37 mm. with a range from 20 to 58 mm. Before considering the pulse pressures with Squad A we may advantageously examine those with Squad B. These show a slight tendency to fall (7 mm. on the average) as the restricted diet progressed and increased in only two cases. With Squad B, the normal pulse pressure was not far from 37 mm. Comparing this value with the pulse pressures for Squad A given in table 76, we find that with the prolonged reduction in diet there is a tendency toward much lower pulse pressures with not a few of the men in this squad. *Bro* shows a low pulse pressure of 15 mm. in many of the measurements, *Can* one record of 15 mm., *Kon* two records of 5 mm., and *Gar* two records of 15 mm. The lowest record for *Gul* was 25 mm., *Mon,* 10 mm. *Moy,* 5 mm., *Pea,* 25 mm., *Pec,* 10 mm., *Spe,* 15 mm., *Tom,* 15 mm., and *Vea,* 25 mm. The group averages in the last column of the table show that the pulse pressures regularly decreased from 34 mm. on October 13 to 18 mm. on December 19, but after the return from the Christmas vacation, the pulse pressure rose for the whole squad to 25 mm. with the two final values somewhat higher, *i. e.*, 30 and 31 mm. It is quite clear that a large proportion of the values shown in table 76 are distinctly lower than normal; hence we may consider that as a result of the low diet there was a definite tendency towards a decrease in the pulse pressure, as well as an absolute decrease in not only the systolic but likewise the diastolic pressure. *Pea,* a well-trained athlete, retained a remarkably constant pulse pressure throughout the entire series of observations. That the pulse pressures of Squad A are noticeably lower than those of Squad B is clear in spite of the almost identical systolic, diastolic, and pulse pressures of both squads on the first day of the experiment. The relationship between these lower values and the exact metabolic level is worthy of special attention in further work.

MODERATE MUSCULAR WORK AND BLOOD PRESSURE, SQUAD A.

It is especially important to note the influence of moderate activity upon the heart, particularly upon the blood pressure, as shown by careful measurements of blood pressure prior to a walking period and immediately following the walking period for the several men. To secure a base-line, the cuff was adjusted prior to the walking test and

a number of observations made with the subject in the standing position. After the completion of the walking, which usually occupied about 26 minutes, the cuff was immediately inflated and both the systolic and diastolic blood pressures noted. At the end of one minute a second observation was made, and the observations continued at intervals for 2 to 2½ minutes. These measurements, it is only fair to state, were taken under very great tension on the part of all operators and are not so free from extraneous influences as one could wish. Furthermore, the cuff had to be repeatedly inflated somewhat rapidly, and there was hardly time for the circulation to be fully established in each case.[1] On the other hand, it is highly improbable that with the group of men as a whole, any disturbance of the general picture could have been made by a fault in technique. The readings were frequently checked by one of us and we have every confidence that they were both taken and recorded as accurately as they could be under the experimental conditions. We believe that they present a true picture of the blood pressures immediately following walking at a rate of about 69 meters per minute. The effects of walking upon the action of the heart will be further considered in the discussion of the pulse-rate. (See p. 440.)

Although the first records of the blood pressures before and after walking were those for Squad B on the morning of January 28, we shall first discuss the values found with Squad A on the morning of February 3, 1918. These are given in table 78, in which both systolic and diastolic pressures and pulse pressure are recorded for each of the 11 men immediately before and after walking. Usually two additional observations were made after the cessation of walking at about the fifth and ninth minutes with the subject sitting. The systolic blood pressures as measured on these men in the standing position before work on the morning of February 3 may first be compared with the records made by Dr. Goodall on the evening of February 2 for the sitting position. The systolic pressures on the morning of February 3 averaged 101 mm., the highest being 107 mm. with *Mon* and the lowest 97 mm. found with 4 of the subjects. Examining the sitting blood pressures found the preceding evening (see those for February 2 in the lower part of table 76), we find that the values tend to be somewhat below 100, with an average of 95 mm. The highest, 100 mm., was found with *Can*, *Gar*, *Moy*, and *Vea*, and the lowest, 90 mm., with *Bro*, *Gul*, *Pea*, and *Pec*. Although the effect of posture on blood pressure is the subject of much discussion, the morning systolic blood pressures are reasonably well checked by these observations of the evening before. The morning values for the systolic blood pressure taken just before walking are therefore in all probability not far from the true values.

[1] This criticism also applies to the technique used by Cotton, Rapport, and Lewis, Heart, 1917, 6, p. 269.

TABLE 78.—*Blood-pressure measurements prior to and immediately after 24 minutes of level walking on a treadmill—Squad A, February 3, 1918.*

Subject and measurement.	Standing.						Sitting.	
	Average before walking.	After walking ended.					After walking ended.	
		½ min.	1 min.	1½ min.	2 min.	2½ min.	5 min.	9 min.
Bro:	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Systolic	97	100	100	100	98	....	100	96
Diastolic	81	78	76	82	82	....	80	78
Pulse pressure	16	22	24	18	16	....	20	18
Can:								
Systolic	97	108	108	106	104	....	104	104
Diastolic	74	72	76	78	78	....	76	80
Pulse pressure	23	36	32	28	26	....	28	24
Kon:								
Systolic	106	102	104	104	104	....	102	98
Diastolic	78	80	86	88	86	....	80	78
Pulse pressure	28	22	18	16	18	....	22	20
Gar:								
Systolic	106	110	110	110	110	108	106	106
Diastolic	71	62	64	70	74	76	70	68
Pulse pressure	35	48	46	40	36	32	36	38
Gul:								
Systolic	104	100	100	102	100	....	98	102
Diastolic	76	66	68	68	70	....	66	66
Pulse pressure	28	34	32	34	30	....	32	36
Mon:								
Systolic	107	106	106	108	108	....	106	104
Diastolic	72	66	68	70	70	....	68	72
Pulse pressure	35	40	38	38	38	....	38	32
Moy:								
Systolic	102	110	112	112	112	....	108	106
Diastolic	68	70	68	70	72	....	66	70
Pulse pressure	34	40	44	42	40	....	42	36
Pea:								
Systolic	97	100	100	98	96	....	100	100
Diastolic	79	60	58	56	54	....	66	72
Pulse pressure	18	40	42	42	42	....	34	28
Pec:								
Systolic	97	106	106	102	102	....	100	102
Diastolic	60	76	76	76	76	....	68	66
Pulse pressure	37	30	30	26	26	....	32	36
Tom:								
Systolic	99	102	102	100	100	98	98	100
Diastolic	75	66	68	70	70	72	70	72
Pulse pressure	24	36	34	30	30	26	28	28
Vea:								
Systolic	100	100	100	102	100	100	98	102
Diastolic	64	68	70	70	72	74	66	66
Pulse pressure	36	32	30	32	28	26	32	36
Average:								
Systolic	101	104	104	104	103	....	102	102
Diastolic	72	69	71	73	73	....	71	72
Pulse pressure	29	35	33	31	30	....	31	30

The diastolic blood pressures likewise show values in the morning which are, as a rule, higher than those found the evening before. That is, in the morning records with the subject standing we find the diastolic blood pressure ranges from 81 mm. with *Bro* to a

minimum of 60 mm. with *Pec*, the average value being for the morning 72 mm. The average of the records made by Dr. Goodall the evening before is 64 mm. Nevertheless, the appearance of values as low as 60 mm. in the case of *Pec* and 64 mm.in the case of *Vea* is a reasonable control upon the low values found the evening before.

The pulse pressures taken before work on February 3 are not unlike those found the evening before. The morning pulse pressures, with the subject standing before work, range from a minimum of 16 mm. with *Bro* to a maximum of 37 mm. with *Pec* and average 29 mm. On the evening before they ranged from a minimum of 20 mm. with *Pec* to a maximum of 40 mm. with *Moy* and *Vea*, and average 31 mm. A somewhat interesting fact is that *Pec* had the minimum pulse pressure in the evening but gave the maximum value the next morning prior to walking.

The effect of work upon the blood pressure can in this series of measurements be noted only in the measurement of the blood pressure in the first quarter minute after the cessation of walking. These values are likewise recorded in table 78. In this first observation immediately after work a slight tendency is shown for the systolic pressure to rise in nearly all cases, although only a few millimeters, the most pronounced rise being 11 mm. with *Can*. In three cases there is a slight fall. Comparing the average systolic pressure for the 11 men the first quarter minute after the end of work with that measured before work, we find a rise of but 3 mm., *i. e.*, from 101 to 104 mm. The course of the systolic blood pressure in the next 2 minutes was essentially constant, there being hardly any changes that are truly significant, although in general there was a very slight tendency for the blood pressure to fall as time progressed. The two observations made with the subject in the sitting position show slightly lower values than those found for the standing. Except for *Can* and *Kon*, the pre-walking blood pressure level was usually regained at the end of 9 minutes. With *Can* the blood pressure remained at 104 mm. as compared with 97 mm. before walking and with *Kon* it was 98 mm. as compared with 106 mm., these men showing diametrically opposite effects. The fact should be noted, however, that the values compared were obtained in different positions.

For comparison with the values cited here, we have systolic blood pressures following walking which were obtained with a normal subject in the standing position in the course of another research some years ago. With this subject (a normal individual walking at the rate of 60 meters per minute for approximately 20 minutes) the general tendency for the systolic blood pressure was to show an increase of 5 to 8 mm. in the first observation after cessation of walking.

With the diastolic pressure for Squad A the immediate effect of work was usually to lower the pressure measurably, although *Pec* shows a rise of 16 mm. Practically all the other men show either a very slight rise or a pronounced fall. A lowering of 9 or more millimeters may be noted in the case of *Gar*, *Gul*, *Pea*, and *Tom*, the fall with *Pea* being 19 mm. The average diastolic pressures before work and the first quarter minute after work were 72 and 69 mm., respectively. The subsequent course of the diastolic blood pressure usually tended towards a slight rise, being in 9 cases higher at the end of 2 minutes than at the end of the first quarter minute. With *Gar* it rose from 62 to 76 mm. in 2.5 minutes and with *Tom* from 66 to 72 mm. With most subjects there was a tendency for the diastolic blood pressure to fall when the sitting position was assumed. At the end of 9 minutes after work, with the subject in the sitting position, the diastolic pressure was usually not far from that for the standing position prior to work, although some rather striking exceptions to this may be noted in the cases of *Gul*, *Pea*, and *Pec*. Especially worthy of note are the low values of 58, 56, and 54 mm. noted with *Pea*. These values are absolutely lower than any diastolic blood pressures heretofore noted with this subject, the lowest diastolic value shown in table 76 with this man being 60.

The immediate effect of work on the pulse pressure was in all but three instances a noticeable rise to an average pulse pressure of 35 mm. as compared with 29 mm. before work. The greatest rise was found with *Pea*, the pulse pressure changing from 18 to 40 mm., *i. e.*, an increment of 22 mm. *Kon*, *Pec*, and *Vea* show falls of 6, 7, and 4 mm., respectively. The subsequent records indicate a definite tendency for the pulse pressure to fall as time passed. No great difference is noted when the subject changed to the sitting position. At the end of 9 minutes the pulse pressure is usually not far from that prior to work, except in the values found for *Kon*, *Gul*, and *Pea*.

MODERATE MUSCULAR WORK AND BLOOD PRESSURE, SQUAD B.

Observations on systolic, diastolic, and pulse pressures were made with Squad B before and immediately after walking on the morning of January 28, 1918. The data secured are recorded in table 79. A comparison of the values for the systolic pressure before walking with those obtained with the same subjects the evening before, (see table 77) is of interest. For the most part there is no great difference between the two series although certain of the men, particularly *Kim* and *Sch*, show very considerable increases over the evening record. The average for the systolic pressure for the evening of January 27 was 94 mm. and for the morning of January 28, 101 mm.

The effect of walking was determined, as before, by observing the blood pressures in the first 15 seconds after the cessation of walking.

TABLE 79.—*Blood-pressure measurements prior to and immediately after 24 minutes of level walking on a treadmill—Squad B, January 28, 1918.*

Subject and measurement.	Standing.						Sitting.	
	Average before walking.	After walking ended.					After walking ended.	
		½ min.	1 min.	1½ min.	2 min.	2½ min.	5 min.	9 min.
Fis:	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Systolic	103	98	98	96	96	....	100	100
Diastolic	79	64	62	70	74	....	76	78
Pulse pressure	24	34	36	26	22	....	24	22
Har:								
Systolic	103	108	108	....	108	....	106	100
Diastolic	82	78	76	....	78	....	76	78
Pulse pressure	21	30	32	....	30	....	30	22
How:								
Systolic	102	110	112	110	112	....	108	106
Diastolic	71	70	74	74	75	....	70	70
Pulse pressure	31	40	38	36	37	....	38	36
Ham:[1]								
Systolic	99	106	104	106	106	....	102	100
Diastolic	83	78	80	80	80	....	80	82
Pulse pressure	16	28	24	26	26	....	22	18
Kim:								
Systolic	101	106	106	104	104	102	100	102
Diastolic	82	78	78	80	82	84	78	80
Pulse pressure	19	28	28	24	22	18	22	22
Lon:								
Systolic	97	110	112	108	106	....	102	100
Diastolic	70	78	78	78	76	....	72	72
Pulse pressure	27	32	34	30	30	....	30	28
Sch:								
Systolic	120	90	92	94	94	....	100	102
Diastolic	78	60	70	72	72	....	70	66
Pulse pressure	42	30	22	22	22	....	30	36
Liv:								
Systolic	88	98	96	96	92	....	96	94
Diastolic	62	66	70	72	76	....	74	78
Pulse pressure	26	32	26	24	16	....	22	16
Sne:								
Systolic	106	100	102	102	102	102	100	102
Diastolic	85	66	66	70	74	76	74	74
Pulse pressure	21	34	36	32	28	26	26	28
Tho:								
Systolic	93	98	100	100	98	....	98	96
Diastolic	81	70	68	68	68	....	78	74
Pulse pressure	12	28	32	32	30	....	20	22
Van:								
Systolic	102	102	102	100	98	....	98	100
Diastolic	81	80	78	78	80	....	78	80
Pulse pressure	21	22	24	22	18	....	20	20
Wil:[2]								
Systolic	98	92	92	93	94	....	90	90
Diastolic	78	70	70	72	72	....	64	68
Pulse pressure	20	22	22	21	22	....	26	22
Average:								
Systolic	101	102	102	101	101	....	100	99
Diastolic	78	72	73	74	76	....	74	75
Pulse pressure	23	30	29	27	25	....	26	24

[1] *Ham*, standing, 3 min. after walking ended; systolic, 104 mm., diastolic, 80 mm., pulse pressure, 24 mm.

[2] *Wil*, sitting, 6 min. after walking ended; systolic, 90 mm., diastolic, 64 mm., pulse pressure, 26 mm.; 10 min. after walking ended, systolic, 90 mm., diastolic, 66 mm., pulse pressure, 24 mm.

The systolic pressures for four of Squad B were somewhat lower in the first quarter minute than they were before work, but with the majority of the men they were perceptibly higher. The averages show, however, practically no change, being 101 mm. before, and 102 mm. for the first quarter minute after.[1] It is to be noted, however, that whatever level the systolic blood pressure assumed after walking, it remained reasonably constant for at least 2 minutes with practically all of the men. As was found with Squad A no pronounced change in systolic pressure was noted with the men in Squad B when they assumed the sitting position.

The values for the diastolic pressures, when compared with those found the evening before, are almost always considerably higher, the most striking case being that of *Ham*, whose diastolic pressure the evening before was 55 mm. and in the morning prior to walking was 83 mm. The average diastolic pressure the evening before was 64 mm.; in the morning it was 78 mm. The immediate effect of walking was, in general, to lower appreciably the diastolic pressure at the end of the first quarter minute. This is in conformity with the findings noted with Squad A. Although with Squad A four cases of positive increment were found, with Squad B there were only two cases that did not show a measurable fall. The course of the diastolic pressure during the succeeding minutes tended almost uniformly to rise slightly. Thus, the diastolic pressure at the end of the second minute was in 8 instances higher than it was at the end of the first quarter minute, a phenomenon likewise observed in about the same degree in the case of Squad A. The increase between the first quarter minute and 2 or 2.5 minutes was 10 mm. in the case of *Fis*, 12 mm. with *Sch*, and 10 mm. with *Liv* and *Sne*. These increments are for the most part somewhat greater than those found with Squad A.

In comparing the pulse pressure of the men in Squad B, taken in the standing position before work on the morning of January 28, with that found the evening before with the men in the sitting position, we find that in general the pulse pressure was somewhat lower in the morning than it was in the evening, the evening average being 30 mm., and the morning average 23 mm. This difference is slightly greater than that observed with Squad A, *i. e.*, 7 mm. as against 2 mm. for Squad A. Here again we find that the walking in practically every instance increased the pulse pressure, the one exception being that of *Sch*, his initial pulse pressure being 42 mm. and that in the first quarter minute after walking 30 mm. The subsequent course of the records following work shows a distinct tendency for the pulse pressure to become somewhat smaller as time went on, and at the end of 9 minutes with the subject in a sitting position the

[1] The increases of 3 mm. with Squad A and 1 mm. with Squad B are wholly incomparable with the normal rises recorded by Cotton, Rapport, and Lewis (Heart, 1917, 6, p. 269) of 15 to 45 mm., although both the kind and amount of work in the several cases are not strictly comparable.

pulse pressure approximated that prior to walking. Three exceptions to this, however, should be noted. That is, with *Sch* the pulse pressure, which was 22 mm. at the second minute after walking, rose with sitting and at the end of 9 minutes was 36 mm. It will be remembered that *Sch* was the one man who showed a pronounced fall in pulse pressure after the walking. With *Liv* the sitting pulse pressure at the end of 9 minutes was considerably less than that found prior to walking, although the values for both systolic and diastolic pressures found with him prior to walking are open to some question on technical grounds. With *Tho* the pulse pressure of 12 mm. prior to walking is likewise open to suspicion; the level noted at the end of 9 minutes was 22 mm.

GENERAL CONCLUSIONS REGARDING BLOOD PRESSURE.

The decreases in blood pressure for all of the men in both Squads A and B, which were found for both systolic and diastolic pressures, as well as for the pulse pressure, indicate that one of the most pronounced effects of the reduced diet was upon the heart action. The fact that the diastolic pressure fell to 60 mm. or below in so many instances with both squads is surprising, for this is practically the so-called "shock level" observed in cases of surgical shock, which has been extensively studied in recent times in connection with the war. One might infer from this that with these extraordinarily low diastolic pressures the subjects would be distinctly unable to withstand surgical shock. On the other hand, we must bear in mind that this is simply another illustration of the marvelous capacity of the human body to adjust itself to very wide variations. While the safety factor may be very great, it would not necessarily follow that the diastolic pressure noted here would be so greatly affected by surgical shock as would a higher pressure. Indeed, the influence of surgical shock upon such low diastolic pressures as these would seem worthy of experimental study with lower animals.

Owing to other work it was impossible for us to give more specific attention to this important factor, but we feel that tracings should have been obtained and the data regarding blood pressure considerably amplified. In the absence of further information, adequate discussion of this subject is of course impossible. We must therefore content ourselves with recording accurately the data as obtained, in the hope that subsequent experimentation may amplify these and render a clear explanation possible. That these men at weight maintenance could have successfully and vigorously carried out their usual physical activities when the blood pressure was as low as is indicated in the series of observations recorded in tables 76 to 79, is one of the perplexing features of this whole research. The possibility of pronounced alterations in blood pressure in disease by means of dietetic alterations similar to those applied here opens a field for speculation

which must first be thoroughly cleared by careful accumulation of experimental evidence. Diastolic blood pressures so close to the shock level as those observed with several of these men would imply that the dietetic conditions in this research might be somewhat near the border line of safety. Obviously, low blood pressure brought about by dietetic alterations must be thoroughly studied in all its phases before final deductions can be made.

PULSE-RATE.

The intimate relationship between the mechanism of the circulatory system and the total metabolism has been frequently pointed out in publications from the Nutrition Laboratory. The heart rate is, with the same individual, a remarkably significant index of the total metabolism. When it is considered that the total carbon-dioxide production is directly proportional to muscular activity and heat production, and furthermore that the blood must carry away the carbon dioxide and supply fresh oxygen to the tissues, in proportion to the need therefor, it is not surprising that the work of the heart bears a general relationship to the total metabolism. If the systolic discharge from the heart were uniform under all conditions, one could predicate that the pulse-rate would be proportional to the total metabolism. Such a proportionality of relationship, however, is by no means established or to be inferred from experimental evidence thus far obtained.

While a reasonably close correlation between the pulse-rate and the total metabolism of a given individual appears to be substantiated by a large number of experiments, this does not apply in any sense to a comparison of the pulse-rate and total metabolism of different individuals. For example, when a subject has a pulse-rate of 60 at one time and a pulse-rate of 80 at another time, one can be sure that the metabolism will be measurably higher with the higher pulse-rate, but it is by no means certain that subject A with a pulse-rate of 60, even with an equivalent weight and height, will have a metabolism lower than subject B of the same height and weight with a pulse-rate of 80. Indeed, the absence of correlation between pulse-rate and total metabolism with different individuals has been frequently noted and commented on in this Laboratory. On the other hand, a recent biometric treatment[1] of the basal metabolism data of the Nutrition Laboratory has indicated the existence of a slight but apparently significant correlation between these two variables, slightly higher gaseous exchange being associated with higher pulse-rate, even with men and women in complete muscular repose and in the post-absorptive state.

In this research on low diet it was imperatively necessary to obtain every possible index of metabolism or physiological activity

[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 79.

under the varying conditions of normal and restricted diet. Hence we required careful records of the pulse-rate, since it is one of the most important physiological indices. Throughout the entire series of observations pulse-rates were very frequently obtained. Realizing that those found during complete muscular repose and with the post-absorptive condition would be of greatest significance, we invariably secured records of the pulse-rate during the respiration experiments with Squad A which were made each morning at Springfield. Records were also obtained at the conclusion of the night experiments with the large respiration chamber in Boston. For Squad A we have but a relatively few observations of pulse-rate with normal diet for comparison with the records after the diet restriction began. Pulse-rates for Squad B with muscular repose and post-absorptive condition were secured only at the end of the Boston night experiments. As indicated in the section on technique, the pulse-rate was taken chiefly by count at the wrist by an experienced observer, although a number of pulse-rates were recorded photographically with body electrodes and the string galvanometer.

In view of the rather important relationship between pulse-rate and the body position and general physical activity, we have subdivided our pulse measurements into several sections according to the experimental conditions and particularly the body position of the subject: (1) lying in the post-absorptive condition; (2) standard electrocardiograms; (3) lying in the middle of the forenoon or middle of the afternoon prior to bicycle riding; (4) sitting with pulse counted either by the subject himself or by an observer at various times throughout the day, invariably with food in the stomach; (5) standing during respiration experiments, or on the treadmill; (6) reclining after short periods of muscular exertion; (7) in the periods of transition from standing to walking, and walking to standing; (8) during the actual process of walking on the treadmill; and (9) lying after a few minutes of brisk bicycle riding, during a special study of the influence of muscular work upon the return of the pulse-rate to normal.

DAILY BASAL PULSE-RATE WITH LYING POSITION, SQUAD A.

The pulse-rates secured with the subject lying in the post-absorptive condition—*i. e.*, the conditions obtaining during the measurement of basal metabolism—should first be considered. For these we have very complete records for Squad A extending throughout the entire period of observation, namely, from September 27 to February 3, inclusive. These records were secured under uniform conditions and for the most part in Springfield, but a few were made in Boston. The daily averages are expressed in table 80 as pulse-rates per minute. The pulse-rates prior to the morning of October 5 were obtained with the subjects on normal diet. The pulse-rates for subsequent days were recorded

TABLE 80.—*Daily pulse-rate*[1] *of Squad A.*

[Subjects in lying position, without food.]

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av. for squad.
1917.													
Normal diet:													
Sept. 27	....	59	....	56	....	59	58	51	54	55	73	59	58
28	61	....	[2]59	....	55	....	57	46	54	56	64	52	56
29[3]	63	58	[2]53	51	60	69	....	58	....	60	....	51	58
Oct. 1	53	49	[2]53	48	62	59	59	....	48	....	66	....	55
2	....	56	[2]53	44	....	59	54	50	50	57	66	48	54
3	56	....	[2]53	....	60	....	55	49	50	58	69	46	55
4	52	62	[2]54	47	58	60	....	50	....	51	....	44	53
Reduced diet:													
Oct. 5	59	53	[2]56	44	60	60	53	....	47	....	61	....	55
6	....	58	....	48	....	61	51	50	47	49	61	46	52
7	51	....	[2]49	....	64	....	56	42	42	54	61	41	51
8	53	52	[2]50	44	59	58	....	42	....	55	....	45	51
9	56	57	[2]48	44	56	58	55	....	44	....	64	....	54
10	....	52	....	46	....	59	46	41	45	56	64	42	50
11	55	....	[2]52	....	50	....	47	43	46	51	64	41	50
12	50	49	[2]45	47	52	67	....	44	....	57	....	41	50
13[3]	51	48	[2]44	46	59	60	50	....	43	....	62	....	51
15	....	50	....	44	....	53	....	41	39	....	62	41	47
16	53	....	[2]47	....	54	....	46	....	....	48	62	42	50
17	....	49	....	45	....	60	....	38	38	52	....	39	46
18	55	....	[2]45	....	54	....	46	....	45	49	63	....	51
19	....	49	....	46	....	68	45	38	....	53	....	41	49
20	54	....	[2]47	....	52	....	47	38	50	....	56	....	49
21	....	52	....	43	48	59	45	39	....	49	....	40	47
22	51	....	[2]44	....	53	55	46	37	43	....	60	....	49
23	....	54	[2]52	41	55	57	....	40	....	48	....	38	48
24	47	....	....	42	51	54	43	....	40	....	53	....	47
25	52	48	....	44	....	60	....	37	....	47	....	38	47
26	53	49	....	42	57	....	44	....	38	....	58	....	49
27[3]	51	....	[4]55	41	....	62	....	37	....	[5]68	57	37	48
29	....	42	[4]50	....	50	54	....	39	46	....	61	37	47
30	53	....	[4]57	42	....	51	43	....	45	52	....	44	47
31	45	46	44	39	57	....	41	36	....	47	44	....	44
Nov. 1	....	....	....	42	....	54	41	37	39	49	55	41	45
2	....	....	48	....	54	....	40	33	37	45	53	35	43
3	48	46	48	40	48	56	....	38	....	46	....	39	45
4	48	46	46	40	56	45	38	....	34	....	52	....	45
5	....	46	....	39	....	52	36	32	36	47	48	43	42
6	51	....	48	....	45	....	38	36	36	46	50	41	43
7	49	51	41	43	43	52	....	32	....	44	....	41	44
8	54	43	46	42	42	55	37	....	39	....	54	....	46
9	....	50	....	41	....	48	39	35	37	46	54	37	43
10[3]	48	....	38	....	52	....	41	34	37	43	49	34	42
12	52	43	38	40	51	54	....	37	....	50	....	43	45
13	45	42	36	38	53	50	39	....	37	....	51	....	43
14	....	43	....	40	....	48	39	35	40	42	50	37	42
15	52	....	44	....	46	....	35	34	39	46	49	37	42
16	55	44	36	37	45	54	....	35	....	47	....	35	43
17	54	42	33	37	51	50	36	....	35	....	48	....	43
18	....	43	....	39	....	50	39	38	36	48	47	37	42

[1] These observations were made early in the morning at least 12 hours after the last meal and for the most part are averages of a considerable number of pulse-rates taken during the two periods on the respiration apparatus.

[2] These records were obtained with *Fre* who left Squad A on Oct. 25.

[3] Day following this date was an uncontrolled Sunday; no record taken.

[4] *Kon* was on normal diet on this day, and hence this pulse-rate is not included in the average.

[5] *Spe* on Oct. 27 believed he had a touch of grippe; this pulse-rate not included in the average.

TABLE 80.—*Daily pulse-rate*[1] *of Squad A*—continued.

[Subjects in lying position, without food.]

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av. for squad.
1917—*cont.* Reduced diet—*cont.*													
Nov. 19.....	45	....	**35**	....	*39*	....	*36*	**32**	**34**	44	44	**29**	*38*
20.....	52	50	*37*	*38*	*40*	50	....	**33**	....	*40*	....	**32**	41
21.....	52	41	*38*	*40*	*39*	53	*37*	....	**35**	....	43	....	42
22.....	....	42	....	*40*	*40*	54	**34**	*37*	....	43	52	*36*	42
23.....	49	....	**33**	....	49	48	*36*	*37*	**34**	*40*	....	**34**	*40*
24.....	54	42	**33**	*39*	....	....	....	**32**	*36*	46	49	**33**	*40*
25[2].....	56	41	**32**	45	*40*	55	*36*	**33**	**31**	48	46	**34**	41
26.....	53	42	*39*	....	53	52	42	....	*40*	....	57	....	47
27.....	....	57	....	....	56	57	*38*	*36*	*38*	50	47	*36*	46
28[3].....	48	....	*40*	*39*	47	....	*36*	*37*	*38*	45	....	*39*	41
Dec. 3.....	50	49	....	*38*	47	56	....	43	....	48	....	*38*	46
4.....	47	51	....	*40*	51	....	44	*36*	*39*	....	64	*37*	45
5.....	....	51	50	*39*	....	56	*39*	....	**35**	....	58	*38*	46
6.....	46	....	44	....	44	54	*39*	*36*	*38*	48	49	....	44
7.....	47	53	46	*38*	45	52	....	**34**	....	45	....	**30**	43
8.....	50	54	....	**34**	*40*	56	**35**	....	**35**	45	47	....	44
9[2].....	53	49	54	**35**	42	60	44	41	*37*	53	58	*38*	47
10.....	....	52	....	43	....	63	48	*40*	*39*	55	62	44	50
11.....	48	....	53	....	53	....	42	*38*	*39*	51	60	*39*	47
12.....	48	49	44	*37*	46	55	....	*38*	*36*	....	....	*36*	43
13.....	56	50	....	*40*	44	54	42	*40*	....	....	58	....	48
14.....	....	57	....	41	....	51	*38*	*36*	*39*	....	54	*37*	44
15.....	56	....	50	....	44	....	*39*	**35**	*37*	....	51	*36*	44
16.....	49	50	50	*39*	....	54	*37*	*38*	....	....	....	**35**	44
17.....	....	47	*40*	*40*	46	59	44	....	*38*	....	54	....	46
18.....	50	49	....	*40*	44	53	....	....	....	....	....	**34**	45
19.....	56	....	41	....	43	....	43	*38*	*37*	....	50	*38*	43
20[2].....	....	50	....	*40*	44	59	46	*37*	*37*	....	49	**35**	44
1918.													
Jan. 7[4].....	....	68	....	51	53	65	....	46	42	....	....	....	54
8.....	54	55	....	....	....	61	43	44	56	....	....	45	51
9.....	52	63	....	47	58	....	60	....	47	....	....	43	53
10.....	....	57	....	50	47	59	46	41	....	....	....	....	50
11.....	53	57	....	....	....	52	46	*40*	43	....	....	42	48
12.....	48	53	61	45	46	....	....	*40*	....	....	74	....	52
13[2].....	52	49	52	44	45	57	46	*39*	41	....	66	*40*	48
14.....	....	....	49	44	60	53	....	....	**34**	....	70	*39*	50
15.....	49	48	58	46	56	60	....	....	....	....	....	*37*	51
16.....	46	51	....	....	....	....	42	*39*	*37*	....	69	**35**	46
17.....	....	....	45	41	47	49	46	*39*	*40*	....	....	....	44
18.....	46	49	48	43	53	....	....	....	....	....	69	**33**	49
19.....	47	47	44	....	....	58	*39*	*40*	....	....	....	*38*	45
20.....	....	....	....	*40*	43	59	41	*40*	....	....	59	....	47
21.....	41	43	....	....	*40*	51	....	....	*36*	....	63	**34**	44
22.....	....	55	46	*39*	....	....	*37*	**35**	**35**	....	60	....	44
23.....	42	....	48	**35**	....	49	....	....	....	....	58	*37*	45
24.....	43	....	44	....	....	....	44	*40*	*37*	....	....	**32**	*40*
25.....	....	....	....	37	46	53	*39*	**33**	**35**	....	57	....	43
26.....	43	45	42	**35**	43	53	....	....	....	....	....	**34**	42
27[3].....	49	41	*38*	**35**	46	56	*36*	*36*	**34**	....	56	*40*	42

[1] These observations were made early in the morning at least 12 hours after the last meal and for the most part are averages of a considerable number of pulse-rates taken during the two periods on the respiration apparatus.

[2] Records on this date taken in Boston in the group respiration chamber.

[3] Thanksgiving recess, Nov. 29 to Dec. 2 inclusive.

[4] Christmas recess, Dec. 20 to Jan. 6, inclusive.

TABLE 80.—*Daily pulse-rate*[1] *of Squad A*—continued.

[Subjects in lying position, without food.]

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av. for squad.
1917—*cont.* Reduced diet—*cont.*													
Jan. 28	....	....	....	....	....	....	**34**	**35**	**33**	....	51	....	*38*
29	45	46	*38*	*40*	....	....	....	....	*37*	....	56	*37*	43
30	47	47	....	....	48	55	42	*36*	....	....	....	**35**	44
31	....	....	*40*	*37*	50	....	....	....	....	....	....	....	42
Feb. 1	53	....	....	*37*	48	45	....	*37*	....	....	58	**34**	45
2	47	53	*39*	....	....	....	41	....	*36*	....	63	*36*	45
3[2]	56	48	*39*	*36*	48	55	45	*38*	*37*	....	60	**35**	45
Max.	63	[3]68	[3]61	56	64	69	[3]60	58	[3]56	60	[3]74	59	62
Min.	41	41	**32**	**34**	*39*	45	**34**	**32**	**31**	*40*	43	**29**	*37*
Diff.	22	27	29	22	25	24	26	26	25	20	31	30	25

[1] These observations were made early in the morning at least 12 hours after the last meal and for the most part are averages of a considerable number of pulse-rates taken during the two periods on the respiration apparatus.

[2] Records on this date taken in Boston in the group respiration chamber.

[3] Note that for these subjects the maximum occurs in January; with the others it appears early in the series.

during the period with the reduced diet. Comparing the rates prevailing at the beginning of the experiment with normal diet and those at the end of January with reduced diet, we find a pronounced fall in pulse-rate in every instance. This striking reduction in pulse-rate is so great with most of the subjects that frequent observations are recorded of pulse-rates between 35 and 40 per minute and even lower. To lay particular emphasis upon the low rates, all values between 40 and 36 inclusive are printed in italics, and the values of 35 or below in bold-face type. An inspection of the table shows the incidence of the italicized figures as the study progressed. The members of the squad with whom italicized figures occur increase in number with the length of the period of reduced diet until, in the last week in November, 8 of the squad show values of 40 or below. As a matter of fact this represents the minimum pulse for the squad as a whole. At the end of the experiment, 5 men show values of 40 or below, but the number of low counts is somewhat less than those which appear in the table in the latter part of November.

Special emphasis should be laid upon the appearance of the bold-face figures indicating 35 counts or below. These are found with 5 subjects during the month of November and in the latter part of January. Records of 32 or below appear in 4 cases in November and the absolute minimum was clearly and definitely established with *Vea* on November 19 of 29 beats, this record being the average of a series of 6 counts. The actual counts for this particular subject on November 19 were: 30, 29, 29, 28, 29, and 30. Thus we have

four separate counts of 29 or 28. After several months' personal practice in counting his own pulse-rate, in which he had been frequently checked by one of our observers, this subject made a report that on January 31 he counted his pulse while sitting in the class room at 10^h15^m a. m. and found it to be 32 per minute; later at 11^h30^m a. m., after lying down about 4 minutes in his room, he found the pulse-rate as counted by himself to be 28 beats per minute. It thus seems definitely established that we have with this subject a clear case of a pulse-rate which on two occasions was below 30 beats per minute.

The fluctuations in pulse due to the novelty of the situation and slight psychological disturbances are perhaps best shown in the 7 days prior to the reduction in diet. In a sense, the average of these days may be considered as the average resting pulse of these men prior to dietetic restriction. In the majority of cases such an average would be legitimate, but in the case of *Vea* the pulse-rate on the first three days is obviously higher than on the last three days of the normal diet period. The period of the lowest pulse-rate with the squad as a whole occurred in the week between November 17 and November 25, inclusive. The average pulse-rate of these men prior to the reduction in diet may profitably be compared with the average for this week to determine the maximum average change in pulse-rate. This is done in table 81.

TABLE 81.—*Comparison of pulse-rate during normal diet with the lowest level of pulse-rate during reduced diet*[1]*—Squad A.* (Weekly averages.)

[Subjects in lying position, without food.]

Subject.	Normal diet, Sept. 27 to Oct. 4, 1917.	Reduced diet, Nov. 17 to 25, 1917.	Difference between normal and minimum pulse-rate.	Subject.	Normal diet, Sept. 27 to Oct. 4, 1917.	Reduced diet, Nov. 17 to 25, 1917.	Difference between normal and minimum pulse-rate.
Bro.....	57	52	5	Pec......	51	34	17
Can.....	57	43	14	Spe......	56	44	12
Gar.....	49	40	9	Tom.....	68	47	21
Gul.....	59	43	16	Vea......	50	34	16
Mon.....	61	51	10				
Moy.....	57	36	21	Av...	56	42	14
Pea.....	51	35	16				

[1] See table 80 for the material from which these data have been drawn.

Using as a basis of comparison the average pulse-rate from September 27 to October 4, when the subjects were on normal diet, we find in all cases a fall in pulse-rate due to the diet, although the differences, of course, are not so large as the differences between the maximum and minimum noted in table 80. The smallest drop was with *Bro* (5 beats) and the maximum with *Moy* and *Tom* (21 beats). On the average the pulse-rate was lowered 14 beats or 25 per cent.

It is thus seen that the general picture of a marked fall in pulse-rate is indicated in every case; the only variations are in the degree of the fall. A comparison between the maximum normal pulse and the minimum pulse found on any day of reduced diet would indicate the maximum variations for the subjects.

When it is remembered that the pulse-rates recorded in table 80 are the average of not less than 3 and for the most part 6 or more counts, it is seen that we deal here not with isolated 1-minute counts, but with a true representation of the pulse level for that particular day. That fluctuations occurred from time to time from uncontrollable causes, even during the morning, was frequently noted by some of our observers. Such illustrations were sometimes recorded by one of the student observers, Mr. Charles Wesley Davis, who assisted in the pulse counts at Springfield. From his thesis prepared in connection with his college work, we have selected for record here the following instances of somewhat rapid changes in pulse-rate during the morning experiments.

On October 24, while *Pec* was resting on the cot during the morning experiment, a sudden nervous impulse caused him to kick his leg. As a result, his pulse-rate jumped from 42 to 52 for a minute. When *Kon* first came on the squad for experimentation, Dr. Roth spoke to him about keeping awake. His pulse, which had been 44, immediately went to 58. *Gul* had a habit of taking occasional deep yawns during his morning tests. His pulse always went up after such a yawn, his average rise being from 6 to 10. *Mon* and *Tom* were examples of men whose pulse fluctuated at intervals for no apparent reason. Upon questioning the men, it was often found that they had been thinking of something exciting. A striking example of the psychical effect upon the pulse was noted with *Gar* on November 14. His pulse-rate rose from 36 to 50, yet he remained perfectly quiet. He admitted later he had been thinking about an examination that was due on the same morning and was doubtful about his knowledge of the subject. *Mon's* pulse showed sudden and wide variations from slight changes in body position. When he first lay down on the cot January 30, his pulse was 56 per minute. Eleven minutes later he was asleep with a pulse-rate of 46. After he changed to another cot and the mask was attached for the respiration experiment, his pulse went to 54.

The maximum and minimum pulse-rates, with differences, are shown at the bottom of table 80. Usually the maximum occurred during the first week, when the subject was on a normal diet. Certain exceptions to this are noted in the footnotes. In some instances the pulse-rate was reduced nearly one-half, notably so in the case of *Vea* and *Kon*. It should furthermore be noted that the maximum with *Kon* occurred immediately after his return from the Christmas holidays. The same is true for the absolute maximum for *Can* and *Tom*. The subsequent course of the pulse during January, however, with neither *Kon* nor *Tom* reached as low a level as was recorded earlier, although with *Kon* a subsequent value as low as 38 was obtained. In general, it

may be stated that, from the data in table 81, the pulse-rate was reduced approximately one-fourth.

Such a striking change in pulse-rate is wholly inconceivable and, indeed, outside the experience of any clinicians with whom we have conferred. Furthermore, the literature rarely mentions pulse-rates as low as were frequently observed in these series, except with primarily pathological cases, and no study of general malnutrition or undernutrition with which we are familiar indicates such profound alterations. We evidently have to deal here with a distinct physiological level, with accompanying conservation of circulatory activity or, as subsequent discussion of the total metabolism will show, the low pulse level is the natural consequence of a lowered metabolism and hence shows a marked decrease in the circulatory activity. In any event, as indications of the pulse-rate of young men who are apparently normal, active and healthy, carrying out with no appreciable reduction in stamina or vigor their intellectual and physical collegiate activities, these values are, we believe, without comparison anywhere in physiological literature.

The tendency for the average minimum pulse-rate to coincide with the minimum food intake and minimum weight may be noted by comparing the dates of the average minimum pulse-rates, namely, November 17 to 25, with the body-weight curves and with the food intake at this time. The subsequent tendency to increase, which became marked during January, is undoubtedly due in part to the freedom allowed the men during the Christmas vacation. On the first day following the Christmas recess *Can*, *Kon*, and *Tom* showed their highest pulse-rates for the whole experiment, *i. e.*, 68, 61, and 74, respectively. With all of the subjects except *Moy* and *Bro*, the first pulse-rates observed after the Christmas recess were markedly higher than the last rate registered prior to the recess. This increment in the case of *Can* was 18, *Kon* 20, *Gar* 11, *Gul* 9, *Mon* 6, *Pea* 9, *Pec* 5, *Tom* 25, and *Vea* 10. With *Bro* there was a decrease of 2 and with *Moy* of 3. As a prime indication of the increased metabolism, these increases in pulse-rate may be directly ascribed to the uncontrolled diet during the Christmas recess.

AVERAGE DAILY PULSE-RATE, SQUAD A.

Although the legitimacy may be questioned of comparing daily average values when the number of subjects used for averaging varied, as they do here, since *Fre*, *Kon*, and *Spe* did not serve for the whole period and the daily pulse records are not continuous, even with the other subjects, we have for purposes of comparison included the daily averages in table 80. It will be recalled that the pulse-rate was usually recorded for 9 subjects each morning and that on the few mornings following the experiments in the group respiration chamber in Boston,

the pulse-rates for the entire squad were measured. Usually the averages given in the last column of table 80 are those for not less than 8 or 9 subjects. The maximum average daily value of 58 beats appears on September 27 (the first day of the experiment). This figure represents an average value for 9 subjects. The minimum average daily value of 38 beats is noted twice, first on November 19 and again on January 28. On the latter date, however, the average represents but 4 subjects, while on November 19 daily pulse-rates for 9 subjects are included in the average. Three italicized figures, *i. e.*, 38, 40, and 40, appear in this column between November 19 to 24, and two appear in the last of January.

Beginning with October 7, that is, the third day after the reduced diet began, the average pulse-rate drops to 51 and continues to be reasonably uniform throughout October. There is a fall to 44 on October 31 and until November 19 the rate remains not far from 44. There is then a short period of low values, but throughout the month of December the average value of 44 or 45 beats is almost uniformly noted, the exceptions being December 9, 10, 11, and 13. A striking increase in the average value is noted on the first few days after the Christmas recess, January 7 to 9, when values of 54, 51, and 53 are found. There is then a progressive decrease, the lowest level occurring from about January 24 to 28, with a tendency for a slight rise thereafter. Apparently when these men are on their maintenance diet at the lower level, the average pulse-rate for the entire group is not far from 43 or 44 beats per minute. While, as we have stated, this method of averaging is open to criticism, the general influence of the reduced diet upon the squad as a whole is fairly well depicted by this series of daily averages. The daily records for each member of Squad A essentially correspond with the course of the general daily average. While certain of the men did not reach a particularly low level in pulse-rate, they nevertheless showed a general decrease in pulse-rate. With other men in Squad A extraordinarily low values were obtained. The profound influence of the reduced diet upon the pulse-rate is thus shown by inspection of the figures for the individual men, but it is shown by the daily averages more clearly and with less contamination by minor extraneous factors.

Save on a few days, all of the pulse records in table 80 were taken at Springfield. On certain of the Sundays in Boston pulse-rates were taken in the group chamber before the subjects rose in the morning. When compared, we find that the Boston values do not differ materially from those obtained on the day before and the day after in Springfield. For instance, on November 25, the average daily pulse-rate for the group obtained in Boston was 41, while the Springfield value for the day before was 40. That for the day following (47) is not unusual, and indicates the rise following the Sunday with uncontrolled diet.

On December 9 in Boston the pulse-rate averaged 47, the day before in Springfield 44, and the following day, also in Springfield, 50. On December 20 the rate obtained in Boston was 44 and the day before 43. On January 13 the rate in Boston was 48, the day before 52, and the following day 50. On January 27 the average rate in Boston was 42, the day before 42, but the following day, only 38. This last average is made up of values obtained from only 4 men, three of whom had consistently low pulse-rates. The final value for February 3 of 45 is the same as that for February 2 obtained in Springfield. The somewhat different conditions obtaining in the Boston experiments (see p. 491) were thus not sufficient to affect materially in either direction the average pulse-rates. It therefore seems perfectly justifiable to include them among the average pulse-rates in table 80.

BASAL PULSE-RATE WITH LYING POSITION, SQUAD B.

Basal pulse-rates were also obtained for Squad B in the group respiration chamber in Boston, both for the normal period and during restriction in diet. They find subsequent use in a comparison of the positions of lying and standing on page 413. Although fewer in number than those of Squad A, they deserve presentation here, and are recorded in table 82. It will be seen that on two days the sub-

TABLE 82.—*Basal pulse-rate*[1]—*Squad B.*

[Subjects in lying position and without food.]

Date.	Fis.	Har.	How.	Ham.	Kim.	Lon.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av. for squad.
Normal diet:													
Dec. 16, 1917[2]	....	48	60	55	....	54	....	52	51	52	47	62	53
Jan. 6, 1918[3]	56	60	58	63	59	....	45	60	48	54	54	57	56
Reduced diet:													
Jan. 14, 1918	46	47	50	46	51	47	*40*	51	54	46	47	46	48
Jan. 20, 1918	44	43	44	48	46	47	*36*	*40*	42	43	*39*	42	43
Jan. 28, 1918	*39*	44	*40*	42	48	**35**	**33**	*39*	*40*	*39*	**34**	47	*40*
Maximum	56	60	60	63	59	54	45	60	54	54	54	62	57
Minimum	*39*	43	*40*	42	46	**35**	**33**	*39*	*40*	*39*	**34**	42	*39*
Difference	17	17	20	21	13	19	12	21	14	15	20	20	18

[1] Obtained in group respiration chamber before 6 a. m.
[2] On Dec. 16 three substitutes, not regular members of Squad B, showed the following pulse-rates: *Leo*, 64; *McD*, 54; *McM*, 73.
[3] On Jan. 6, *McM* had a pulse-rate of 63.

jects were with normal diet, although January 6 is characteristic of being the first observation after the Christmas recess. It may not be without significance that the average pulse-rate of this group showed an increase of 3 beats on the return of the men from the Christmas recess; it will be recalled that a pronounced increase was also found with Squad A under these conditions. Of special significance, however, are the values found on the three subsequent days with reduced

diet. On January 14 all the men except *Sne* showed a reduction in pulse-rate from the basal values found on January 6, this reduction for the squad as a whole averaging 8 beats. On January 20 a further reduction was noted in all but two cases, *Lon* showing no change and *Ham* showing an increment of 2 beats per minute. The average decrease for the entire squad was 5 beats. On January 28 a still further reduction was noted. On the average it decreased from 43 to 40, although with 3 individuals the pulse-rate increased on this date. At the bottom of table 82 are given both the maximum and minimum values, together with the differences. The average difference between maximum and minimum is 18 beats, showing for this squad a maximum decrease in the pulse-rate of 18 beats. This is in full conformity with the picture presented by the extensive data with Squad A.

STANDARD ELECTROCARDIOGRAMS.

The pulse-rate data, which have been presented and discussed in preceding pages, were in all cases recorded from counts at the wrist. During the collection of these data, no subject or observer ever noted irregularity at the time of making the pulse counts. There were no apparent cardiac symptoms, even after hard muscular work. (See page 453.) The pulse-rate appeared to decrease with fair regularity with the progress of the experiment. It seemed highly improbable that the slow rates of 35 or less were due to disturbances in conduction such as a regular 2 : 1 heart block, *i. e.*, failure for every other auricular impulse to get through to the ventricles, or to the complete dissociation of auricles and ventricles characteristic of the Stokes-Adams syndrome. In the latter case, it is well known that the independent rate of the ventricles is usually about 32 per minute. Convincing proof in this matter of the normality of heart action in these slow pulse-rates associated with reduced diet could of course be had through graphic records, such as electrocardiograms taken under standard conditions.

It was desirable to interfere as little as possible with the Boston experimental program. This work could not be done in Springfield, and rather than take electrocardiograms from every subject, it appeared more satisfactory to take such tracings from only the 4 or 5 subjects who showed the slowest pulse-rate. Connections were therefore arranged from the string galvanometer in the main psychological laboratory to the group respiration chamber in the calorimeter room. The electrodes used in the respiration chamber were of the non-polarizable, wick form. A long strip of cotton gauze soaked in a saline solution was wrapped about the arm and the end of this dipped into a vessel of the saline solution. The distance between the arm and the vessel was about 7 inches. A porous clay cup containing the amalgamated zinc electrode and zinc sulphate was also placed in the vessel of saline solution. Such electrodes were connected with each arm, while

the left foot of the subject was placed in a vessel of saline solution. On the morning of December 20, when the subjects were in the post-absorptive condition and before any of them were awake, the observers entered the chamber to connect them in turn to the string galvanometer. They had, of course, previously been informed what was to be done. It was, however, impossible to connect a subject without waking him and without stimulating the circulation more or less. The men remained very quiet; most of those who were not used as subjects continued sleeping. Tracings from the three standard leads were taken for *Kon*, *Pea*, and *Pec*. Even though the arms and left foot were bathed in an alcohol solution to reduce the tissue resistance, this remained, in general, quite high, *i. e.*, from 4,000 to 9,000 ohms, in spite of the fact that an interval was allowed for the skin to become soaked and in good conducting condition.

Even with three observers cooperating it required some time to secure satisfactory tracings from a subject, and since tissue resistance under these conditions was higher than desired, it was decided to continue taking the records with the subject reclining in a steamer chair rather than lying on his back. Both arms and the left foot were placed in large pans of saline solution, which were arranged as non-polarizable electrodes. In this way a minimum of time was required in adjusting the subject to the electrodes, and there was a good opportunity for him to become relaxed and indifferent to the conditions. Thus, in the later records of the morning of December 20, the subject walked up the steps out of the respiration chamber and down another stairway to the level of the floor, stopped at the urine jar, and then came directly to the psychological laboratory, where he reclined in a steamer chair. Tracings from the three standard leads were taken in this position for *Bro*, *Kon*, *Moy*, *Pec*, and *Vea*. The tissue resistance under this condition ranged from 600 to 3,500 ohms.[1]

On February 2 at 4 p. m.—*i. e.*, just before the standard evening meal—three of the subjects on whom electrocardiograms had previously been taken came to the Laboratory again for this purpose. These men, *Kon*, *Pea*, and *Vea*, were selected as their pulse-rates were as low as those of any in the squad, if not, indeed, the lowest; furthermore, as these subjects had served in this capacity previously, they would be but little affected by the novelty of the procedure. Arrangements were made on the balcony in the psychological laboratory so that the men could recline upon cots for about 20 minutes before the tracings were taken. The immersion electrodes were again used, and the men reclined in a steamer chair for the measurements. The tissue resistance ranged from 800 to 2,000 ohms; in general the conditions seemed very favorable.

[1] Duplicate records were taken for *Pec* and *Kon*, since those made when these subjects were in the respiration chamber were under conditions of 9,000 and 8,000 ohms tissue resistance, respectively.

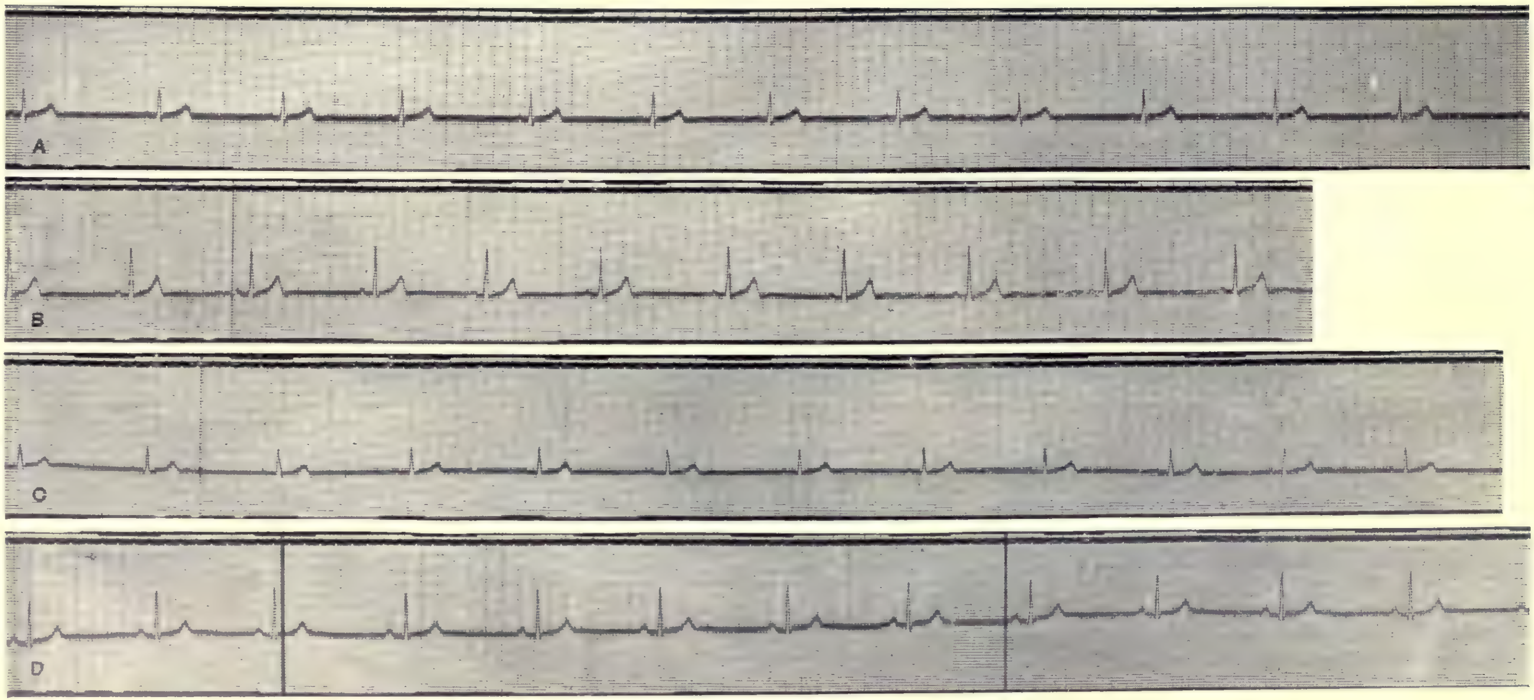

FIG. 90.—Electrocardiograms for *Kon* and *Pec*.

A, *B*, and *C*, from L^1, L^2, and L^3 for *Kon* in group chamber, resistance 9,000 ohms; *D* from L^2 for *Pec*, in group chamber, resistance 8,000 ohms.

The tracings for the two days from the standard leads designated L^1, L^2, and L^3 are shown in table 83 as pulse-rates per minute. These range from 35 to 54; in the case of every subject lower pulse-rates were found at some other time during the investigation. This would naturally be expected. The subjects were thoroughly accustomed to having the pulse counted at the wrist, but this was not the case with the electrocardiographic tracings. Furthermore, both of the dates, December 20 and February 2, came at the end of a period of weight maintenance, during which time the amount of food was somewhat larger than at other periods. Since there was a noticeable correlation between the height of the pulse-rate and the energy intake, it could not be expected that the pulse would be as low here as it was, for example, at the middle of November. Nevertheless, the pulse-rates in the tracings which were made are mostly on a definitely lower plane than is commonly accepted as the normal pulse-rate for men of this age. The records taken in the chamber before the men got out of bed show especially slow rates, being 35 to 38 for the three men, *Kon*, *Pea*, and *Pec*.

TABLE 83.—*Pulse-rates shown by the standard electrocardiograms.*

Place and date of taking records.	Subjects.	L^1	L^2	L^3
Chamber, Dec. 20..	Kon.....	*38*	*38*	*38*
	Pea......	35	*36*	*37*
	Pec......	*37*	*37*	*37*
Room C, Dec. 20...	Bro......	52	53	54
	Kon.....	39	*40*	*40*
	Moy.....	51	51	53
	Pec......	43	44	46
	Vea......	42	41	*40*
Room C, Feb. 2....	Kon.....	43	43	46
	Pea......	46	47	46
	Vea......	46	47	44

If there were any pathological conditions to be found in the electrocardiographic tracings with the subjects on whom we took records in this low diet investigation, we would deem it necessary as important data of the experiment to publish all the tracings. Several of the tracings with explanatory legends are presented in figures 88, 89, and 90. In selecting the illustrations our only preference was to show those tracings which demonstrated the slower pulse-rates. Only normal electrocardiograms were shown by all of the subjects in every lead.

The usual chief deflections, *P*, *R*, and *T*, are present in their normal sequence and with no appreciably altered time relations. The waves are regular and of usual amplitude, and in no case is any certain wave absent or present in excessive number, that is, there are no extra systoles. There is no pathological arrhythmia, and absolutely no indication of heart block. Thus it is certain that the standard electrocardiograms demonstrate no abnormality other than the slow rate. The condition would appear to be classifiable as a sinus Bradycardia. This condition of slow, regular pulse-rate is known to occur normally in convalescence, old age, and pregnancy. These standard electrocardiograms taken in connection with our research seem to demonstrate that sinus Bradycardia may also normally occur with a lowered

metabolism resulting from reduced diet. Since the electrocardiograms indicate normal heart action, it would appear that in addition to such factors as sex and age we must also add nutritional level as exercising a prominent influence upon the pulse-rate level. It is important that the conditions found in this experiment may exist with no cardiac discomfort or dyspnea.

PULSE-RATE, WITH LYING POSITION, PRIOR TO WORK OF BICYCLE RIDING.

The pulse-rates thus far considered were all obtained with the subject lying in the morning before breakfast and represent the minimum basal values.[1] In connection with the study of the return of the heart to normal after a definite amount of moderately vigorous physical exercise, Professor A. G. Johnson, of the faculty of the International Y. M. C. A. College at Springfield, determined the pulse-rates of the subjects in the lying position. His procedure in these experiments was as follows: After the subject came to the room containing the ergometer, he lay down on a table and the radial pulse was taken every minute until at least three successive observations gave the same rate. This usually required from 4 to 10 minutes. During this time the subject was required to lie quietly with muscles relaxed. He was then placed on the ergometer. After riding the man got off quickly and again lay down on the table, this change of position taking about 5 seconds. Subsequently the pulse was counted during the first 15 seconds of each minute until the rate became normal.

At present we are primarily interested in the pulse values recorded with the subject in the lying position prior to the work. The first observations under these conditions were obtained on October 19 and usually followed at 3 or 4 day intervals throughout the rest of the study, excluding the Christmas recess. In considering these pulse-rates it should be borne in mind that they were obtained after a relatively short period of relaxation. The ergometer was in a room on the second floor of the gymnasium. Frequently the subjects ran rather rapidly up the steps to this room, and it is conceivable that the time allowed for the pulse to reach normal, namely 4 to 10 minutes, was hardly long enough. On the other hand, as the increment due to riding was frequently over 100 per cent, the values were sufficiently exact as a base line for Professor Johnson's study.

These pulse values also differ from those previously discussed as the subjects were not in the post-absorptive condition. All observations were taken between the hours of 9^h30^m and 11^h30^m a. m., and 1^h30^m and 4^h30^m p. m., *i. e.*, from 2 to 4 hours after the last meal. Under these conditions the pulse-rate was undoubtedly influenced to a certain extent by food ingestion which would tend to increase the values. Since each man usually came for his test at approximately

[1]Some of the electrocardiograms, as previously noted, were not taken under these conditions.

the same hour of the day, the results are more or less comparable with one another.

Bro, *Gul*, and *Gar* of Squad A did the work on the ergometer between the hours of 9^h30^m and 11^h30^m a. m. The rest of the men in Squad A came in the afternoon between 1^h45^m and 4^h30^m o'clock, nearly always in the following order: *Pec, Vea, Can, Moy, Spe, Mon, Tom, Kon,* and *Pea*. In Squad B, *How, Ham, Wil,* and *Liv* always came between 9^h30^m and 11 a. m. The rest of Squad B came between the hours of 2 and 4^h30^m p. m., as follows: *Sne, Van, Har, Tho, Lon, Fis, Sch* and *Kim*.

PULSE-RATE, LYING BEFORE WORK, SQUAD A.

The normal pulse-rates of the subjects in Squad A prior to the bicycle-ergometer experiments, as recorded by Professor Johnson, are given in table 84. Unfortunately these interesting values were not obtained during the normal diet period, as the records did not begin until October 19, when the men had already been upon a reduced diet for practically two weeks. The individual values show, however, a striking tendency toward a falling off in pulse-rate, although, as would be expected, relatively few reached 40 or below, hence the number of italicized figures showing this lower level is proportionately reduced and but few figures in bold-face type are to be noted. Emphasis must again be laid upon the fact that these pulse-rates were no doubt influenced by the presence of food in the stomach and previous moderate exercise.

These pulse-rates, however, are the best pulse records we have of the post-diet condition of the men in Squad A. The restricted diet was discontinued on February 3. Professor Johnson made a series of observations 5 days later (February 8), which are perfectly comparable with those made on January 31. All of the men who were available for observation on the later date showed pronounced rises. The greatest increase is that with *Kon*, whose pulse nearly doubled, rising from 45 to 82. The smallest rise was observed with *Gar*, the increase being from 58 to 66. The average rise for the entire squad was from 48 to 71. A still further average increase was noted on February 11, but constant values were obtained for the following 2 days. From February 20 to March 7, inclusive, there is a definite tendency for a slight falling off in pulse-rate from the higher level of February 11, 15, and 18, so that the average for the last 5 days of observation is not far from 68. The isolated instance of a pulse-rate of 89 obtained with *Tom*, which is included in the average, should be called to attention. Undoubtedly 89 is an aberrant figure which should not legitimately be included in the average, but it is used here, as it represents the absolute highest pulse-rate in the table.

While, therefore, strict uniformity could not be maintained in taking the pulse records in table 84 under the conditions previously noted, especially the prior activity and the food in the stomach, never-

TABLE 84.—*Daily pulse-rate with food*[1]—*Squad A subjects in lying position.*

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Ven.	Av. for squad.	Av. for squad lying without food.[2]
1917. Reduced diet.														
Oct. 19	64	68	....	52	68	64	62	48	80	60	72	60	63	49
Oct. 22	64	52	....	56	62	68	60	42	52	60	64	64	59	49
Oct. 26	60	68	....	52	68	68	62	48	52	72	68	64	62	49
Oct. 29	58	51	[3]56	44	58	64	48	42	47	52	70	69	55	47
Nov. 2	....	48	....	*40*	57	65	70	41	*40*	61	61	66	55	43
Nov. 5	....	53	64	48	51	58	43	44	41	53	58	66	53	42
Nov. 9	56	50	41	45	47	53	49	41	*37*	45	56	58	48	43
Nov. 12	58	48	42	*39*	43	51	*40*	*36*	*38*	58	60	64	48	45
Nov. 16	60	....	*36*	*38*	44	49	41	**34**	....	69	59	*38*	47	43
Nov. 19	45	49	....	50	53	65	*36*	*39*	**34**	46	....	45	46	*38*
Nov. 23	53	45	*37*	53	42	57	41	*40*	*36*	53	60	*40*	46	*40*
Nov. 26	56	46	*36*	....	45	58	*38*	*38*	41	61	67	42	48	47
Dec. 3	51	53	....	....	....	64	45	42	47	56	78	50	54	46
Dec. 7	62	53	42	42	53	56	43	*36*	42	53	58	**35**	48	43
Dec. 10	63	60	49	49	53	74	53	42	41	58	63	41	54	50
Dec. 14	58	....	....	47	52	69	45	*40*	48	....	62	*36*	51	44
Dec. 17	62	50	45	49	53	63	49	42	47	....	63	*37*	51	46
1918.														
Jan. 7	....	....	....	57	....	....	74	48	....	....	....	....	....	.....
Jan. 11	58	54	....	53	58	60	44	46	46	....	....	56	53	48
Jan. 14	....	53	54	49	53	66	49	56	49	....	....	48	53	50
Jan. 18	58	46	46	....	52	62	46	48	53	....	....	**34**	49	49
Jan. 21	51	42	42	45	49	56	*39*	41	42	....	....	**32**	44	44
Jan. 28	49	49	....	42	44	54	42	45	45	....	....	*36*	45	*38*
Jan. 31	48	46	45	58	46	57	57	42	42	....	....	*37*	48	42
Av.	....	....	....	....	....	....	....	....	....	....	....	....	51	45
Unrestricted diet.														
Feb. 8	81	62	82	66	80	82	77	....	60	....	....	53	71	.....
Feb. 11	76	74	....	71	78	88	76	....	74	....	....	76	77	.....
Feb. 15	76	....	....	70	72	85	77	80	80	....	....	86	78	.....
Feb. 18	73	66	....	66	80	80	76	84	88	....	....	74	76	.....
Feb. 20	66	69	....	58	....	85	80	65	73	....	....	64	70	.....
Feb. 25	69	62	....	61	69	73	64	72	77	78	....	57	68	.....
Mar. 1	65	74	....	58	72	74	69	73	75	69	89	64	71	.....
Mar. 4	69	....	....	56	73	77	64	73	74	....	....	60	68	.....
Mar. 6	....	65	....	57	74	74	....	64	....	....	....	56	65	.....
Mar. 7	68	....	....	....	....	....	....	62	....	68	....	....	....	.....

[1] Observations made between 9^h30^m and 11^h30^m a. m. and between 1^h30^m and 4^h30^m p. m. just prior to work on the bicycle ergometer, constancy having been obtained for several counts.
[2] See table 80, p. 385.
[3] *Kon* was on normal diet on this day, and hence this pulse-rate is not included in the average.

theless the picture is reasonably uniform with practically all subjects, showing an effect of the low diet upon the pulse-rate before work and especially a pronounced increase following the resumption of full diet.

The high value of *Moy* on January 7 has an interest, as it will be remembered that in the discussion of the early morning pulse-rates in table 80 he was shown to be one of two men who, on return from the Christmas vacation, had a pulse-rate lower than the last value recorded in December. The post-absorptive pulse-rate of 43 in table

80 was observed during the early morning experiment of January 8, while the high pulse-rate of 74 was recorded immediately before the work experiment of Professor Johnson on the day preceding (January 7). The records indicate that this man returned to Springfield before dinner on January 7 and was a subject for the work test near the middle of the afternoon. Professor Johnson's pulse records during the experiment show that *Moy*'s pulse-rate of 74 prior to work was an average of three countings. Following the work the pulse-rate at the end of 8 minutes was 76 and it finally reached a level of 74 at the end of 9 minutes. These later records seem to verify completely the initial high count. The record of 43 for January 8 in table 80 indicates that the pulse-rate had fallen to a level below his pulse level prior to the Christmas recess. On January 9 the pulse in the early morning was 60. For several weeks subsequent to this date, pulse-rates averaging 42 beats were obtained, with fair agreement between the two series of records.

The same subject (*Moy*) had on November 2 a pulse-rate prior to work of 70 as compared to one of 48 on October 29. Table 80 shows that the pulse-rate of *Moy* in the early morning of November 2 was only 40. We thus have here again a marked difference between the post-absorptive pulse and the pulse-rate prior to work. With the other men, fluctuations as pronounced as this are rarely observed. Attention should, however, be called to the high value of 78 on December 3 with *Tom*. Unfortunately on that particular day there is no post-absorptive pulse value for comparison as his respiratory exchange was not measured that morning; the early morning record for the next day (December 4) was 64.

For further comparison we give in the last column of table 84 the averages obtained for the post-absorptive pulse-rates in the lying position which were recorded in the early morning. (See table 80, p. 385.) Although, of course, the comparison can only be made for the low-diet period, since no early-morning records were made after February 3, these figures show, as would be expected, that the pulse-rate prior to bicycle riding was in all but two cases higher than in the morning. On January 18 and 21, identical values were found both for the pulse in the early morning and for the pulse prior to work, namely, 49 and 44 on the two days, respectively. The difference between the levels of the two series of values may best be observed from the curves for the average normal pulse-rate prior to work and the average basal pulse-rate in the morning given on the chart in figure 91 (p. 411). As indicated by the last two columns of table 84, this difference is usually not far from 3 to 6 beats.

This intimate comparison of these two series of pulse data supplies a logical argument for the scientific recording of pulse-rates only when the subject is in the post-absorptive condition and after a considerable

period of muscular repose. Under these conditions, as may be seen from table 80, striking irregularities are usually avoided and the pulse-rate seems to provide an admirable index of the general metabolic condition.

PULSE-RATE, LYING BEFORE WORK, SQUAD B.

The absence of pulse observations on Squad A prior to the period of diet restriction is a fault in the pulse study with this squad. With Squad B, excepting when they were on low diet January 8 to 28, inclusive, certain values were obtained which make up in part for this deficiency in normal values with Squad A. Thus, beginning October 24, Professor Johnson obtained lying values for the pulse-rate of these subjects prior to work, and as the squad had no diet restriction until January 8, the values between these two dates supply material for comparison. The pulse values recorded by Professor Johnson are given in table 85 for both the normal, restricted, and unrestricted diet periods. The daily averages are given for these subjects as was done for Squad A.

TABLE 85.—*Daily pulse-rate with food*[1]—*Squad B, subjects in lying position.*

Date.	Fis.	Har.	How.	Ham.	Kim.	Lon.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av. daily pulse-rate.
1917.													
Normal diet:													
Oct. 24	64	64	72	72	....	60	....	68	68	60	64	64	66
Oct. 31	61	74	62	58	....	60	....	56	68	58	58	65	62
Nov. 7	60	65	60	60	....	62	....	60	76	56	61	65	63
Nov. 14	60	70	66	65	....	53	....	61	74	57	58	64	63
Nov. 21	54	53	77	69	....	58	....	62	....	59	62	57	61
Dec. 5	....	67	70	63	....	63	....	62	72	56	58	69	64
Dec. 12	....	54	68	58	....	....	....	54	76	52	....	60	60
1918.													
Reduced diet:													
Jan. 9	....	....	66	61	....	54	....	58	67	50	62	58	60
Jan. 16	58	49	57	61	66	49	*38*	44	58	46	46	52	52
Jan. 23	49	45	58	54	58	....	*38*	49	54	44	*37*	*40*	48
Unrestricted diet:													
Jan. 30	....	66	65	72	....	60	53	62	78	56	53	61	63
Feb. 6	....	77	92	66	77	69	64	71	....	56	62	64	70
Feb. 13	76	69	82	73	....	70	....	68	....	54	76	69	71
Feb. 20	50	70	85	58	84	75	....	65	....	....	63	70	69
Feb. 26	62	62	72	58	....	61	....	65	....	57	61	69	63
Mar. 6	57	62	72	68	(2)	(2)	....	61	....	53	49	66	61

[1] Observations made between 9^h30^m and 11^h30^m a. m. and between 11 a. m. and 2 p. m. just prior to work on the bicycle ergometer, constancy having been obtained for several counts.

[2] On March 1 the pulse-rate of *Lon* was 61; of *Kim*, 69.

The pulse-rates of the several men did not vary widely from day to day prior to the period of diet restriction, except in one or two instances, such as with *Har*, whose records varied from 53 to 74. Usually the ranges are within 8 or 14 beats. The average daily rate was 66 for

the first day, when undoubtedly the novelty of the test played some rôle. The subsequent values prior to diet restriction were essentially constant, ranging only from 64 to 60. On January 9, the first observation after the diet was reduced, no great change in pulse-rate was found, save with *Lon* and *Sne*, whose pulse-rate fell 9 beats, a change however, no greater than that observed on previous days with a few subjects. On January 16, however, there was a pronounced fall with practically all of the men save *Ham*, whose pulse-rate of 61 on January 9 and 16 is actually higher than the rate for December 12. The extraordinarily low rates of *Sch* of 38, representing the absolute minimum values found with all the men, except for the isolated figure for *Van* of 37 on January 23, would have been particularly interesting for a comparison with prediet values. Unfortunately no such values were obtained for this subject, as *Sch* did not enter the squad until later in the year. Comparing the average values for the period of restricted diet, we find that although the first record (that for January 9) is the same as the last normal record, *i. e.*, 60 beats, the pulse-rate dropped on January 16 and 23 to 52 and 48, respectively. With the resumption of normal diet the first record (that for January 30) shows a decided increase in pulse-rate in every instance, the most striking being that with *Sne* of 24 beats. The average for the whole squad shows an increase from 48 to 63, or 15 beats per minute. On the next experimental day, February 6, there was a still further increase with all but two men, *Ham*, whose pulse-rate decreased 6 beats, and *Tho*, whose rate did not change. A large increase was noted with *How* from 65 to 92. The average for the squad increased from 63 to 70. On the next two experimental days the average pulse-rate remained essentially the same, but on February 26 and March 6 there was a tendency towards a fall, the average values being 63 and 61, respectively. These later pulse-rates represent values which are probably characteristic of the normal dietetic habits of these subjects.

Thus with Squad B we have a complete duplication of the picture shown with Squad A, except that in this series of records we have also normal values prior to the diet reduction, in addition to the normal values with the resumption of full diet. While the minimum average value with Squad B was 48 as compared with the minimum average value of 44 with Squad A, it is clear that the influence of restricted diet upon the pulse-rate as indicated by both squads was very pronounced.

PULSE-RATE WITH SITTING POSITION.

PULSE-RATE WITH SITTING POSITION, PSYCHOLOGICAL TESTS.

All of the pulse data given in the previous section, save those taken by Professor Johnson and certain of the electrocardiograms, were obtained with the subject in the lying position in the post-absorptive condition and without previous activity. Beginning with December 8,

another series of observations was made in connection with the psychological program at the Laboratory. The series consisted of six records which were taken by wrist counts. No. 1 was taken immediately after the adding test, No. 2 immediately after the pitch discrimination, and No. 3 after the clerical test. These the subjects themselves counted. Nos. 4, 5, and 6 were counted by the experimenter, No. 4 after the finger movements, No. 5 after the patellar reflex. No. 6 was taken the following morning, after the finger-movement test; thus, while the values for this last count are entered under a given date, they actually belong to the following day. The data for the six observations are given in table 86 for Squad A and in table 87 for Squad B.

TABLE 86.—*Pulse data taken in connection with psychological sessions—Squad A, subjects sitting.*

Subject and date.	1	2	3	4	5	[1]6	Subject and date.	1	2	3	4	5	[1]6
BRO.							MOY.						
Dec. 8	77	72	67	68	65	67	Dec. 8	51	52	47	45	44	53
Dec. 19	72	72	66	66	70	([2])	Dec. 19	55	56	54	54	51	([2])
Jan. 12	71	67	61	61	61	60	Jan. 12	54	54	51	57	45	52
Jan. 26	64	62	59	59	60	58	Jan. 26	52	50	41	*40*	*36*	*40*
Feb. 2	72	72	60	57	57	([3])	Feb. 2	60	60	58	44	41	([3])
CAN.							PEA.						
Dec. 8	59	63	51	50	50	58	Dec. 8	47	46	*40*	*39*	35	*40*
Dec. 19	66	66	62	52	50	([2])	Dec. 19	48	44	42	*39*	*36*	([2])
Jan. 12	63	60	59	50	48	60	Jan. 12	61	58	*39*	42	*40*	54
Jan. 26	50	52	46	52	47	54	Jan. 26	45	42	*40*	42	*37*	46
Feb. 2	59	63	56	49	50	([3])	Feb. 2	50	46	45	47	46	([3])
KON.							PEC.						
Dec. 8	51	52	44	44	41	56	Dec. 8	48	48	....	49	41	64
Dec. 19	52	53	48	44	45	([2])	Dec. 19	58	51	44	46	*39*	([2])
Jan. 12	66	66	60	58	52	60	Jan. 12	67	59	54	52	49	58
Jan. 26	44	45	*40*	*36*	35	44	Jan. 26	45	52	52	42	*39*	46
Feb. 2	50	54	42	*39*	*37*	([3])	Feb. 2	52	58	45	44	*40*	([3])
GAR.							SPE.						
Dec. 8	52	56	41	43	41	53	Dec. 8	72	70	60	56	52	65
Dec. 19	60	58	54	49	46	([2])	Dec. 19	....	....	....	....	....	....
Jan. 12	62	65	56	57	52	50	Jan. 12	....	....	....	....	....	....
Jan. 26	49	48	43	*40*	*38*	52	Jan. 26	....	....	....	....	....	....
Feb. 2	58	58	53	48	47	([3])	Feb. 2	....	....	....	....	....	....
GUL.							TOM.						
Dec. 8	66	60	58	54	54	66	Dec. 8	73	79	70	64	60	69
Dec. 19	59	60	45	46	42	([2])	Dec. 19	62	62	57	60	53	([2])
Jan. 12	72	74	72	62	60	67	Jan. 12	86	86	90	88	81	87
Jan. 26	60	54	53	52	50	52	Jan. 26	70	71	70	61	55	74
Feb. 2	68	68	60	53	55	([3])	Feb. 2	74	82	68	67	61	([3])
MON.							VEA.						
Dec. 8	60	55	57	55	53	70	Dec. 8	54	51	*40*	44	*38*	46
Dec. 19	63	66	62	61	58	([2])	Dec. 19	57	62	45	46	45	([2])
Jan. 12	60	51	56	52	48	64	Jan. 12	58	52	47	47	42	52
Jan. 26	62	58	60	54	50	60	Jan. 26	48	*40*	*39*	35	33	42
Feb. 2	56	63	67	49	47	([3])	Feb. 2	52	52	54	47	43	([3])

[1] Taken on morning following date given.
[2] Electrocardiograms taken; no wrist counts made.
[3] Walking experiment in place of psychological measurements.

TABLE 87.—*Pulse data taken in connection with psychological sessions—Squad B, subjects sitting.*

Subject and date.	1	2	3	4	5	[1]6
FIS.						
Jan. 5	70	72	68	68	68	([2])
Jan. 13	74	68	60	65	64	52
Jan. 19	67	68	64	60	61	54
Jan. 27	66	64	50	49	49	([2])
HAR.						
Dec. 15	55	57	56	50	47	63
Jan. 5	67	67	59	62	56	([2])
Jan. 13	60	57	50	51	48	60
Jan. 19	60	60	42	44	43	50
Jan. 27	71	61	51	42	*39*	([2])
HOW.						
Dec. 15	85	81	73	76	68	80
Jan. 5	84	80	....	82	72	([2])
Jan. 13	66	65	56	55	53	76
Jan. 19	70	62	80	56	54	70
Jan. 27	64	56	58	48	43	([2])
HAM.						
Dec. 15	74	76	68	64	64	63
Jan. 5	87	83	73	68	64	([2])
Jan. 13	85	85	62	63	62	58
Jan. 19	69	71	61	65	58	60
Jan. 27	68	64	56	57	57	([2])
McM.						
Dec. 15	88	78	82	68	74	70
Jan. 5	74	72	68	68	69	([2])
KIM.						
Jan. 5	98	98	84	78	76	([2])
Jan. 13	90	84	74	72	70	50
Jan. 19	82	78	61	65	62	64
Jan. 27	74	78	67	57	55	([2])
LON.						
Dec. 15	55	53	56	56	56	56
Jan. 13	68	70	56	58	58	60
Jan. 19	50	52	46	50	47	58
Jan. 27	48	52	44	42	*39*	([2])
MAC.						
Dec. 15	73	72	57	60	62	80
SCH.						
Jan. 5	80	80	60	51	56	([2])
Jan. 13	68	67	46	44	*39*	51
Jan. 19	64	72	44	42	*39*	44
Jan. 27	56	52	64	44	41	([2])
LIV.						
Dec. 15	59	62	60	60	62	60
Jan. 5	64	54	50	53	52	([2])
Jan. 13	60	56	56	50	51	52
Jan. 19	52	48	44	*40*	*39*	56
Jan. 27	52	54	*40*	*37*	*39*	([2])
SNE.						
Dec. 15	77	77	68	72	66	72
Jan. 5	82	80	65	76	66	([2])
Jan. 13	86	80	70	65	70	70
Jan. 19	70	66	64	70	60	68
Jan. 27	72	68	64	64	54	([2])
THO.						
Dec. 15	55	55	56	54	54	56
Jan. 5	....	....	54	53	50	([2])
Jan. 13	52	52	50	47	45	44
Jan. 19	50	50	44	44	44	52
Jan. 27	52	50	44	44	43	([2])
VAN.						
Dec. 15	62	65	55	52	56	58
Jan. 5	70	70	....	60	58	([2])
Jan. 13	70	70	58	60	58	46
Jan. 19	58	54	42	42	41	44
Jan. 27	56	58	43	*39*	*39*	([2])
WIL.						
Dec. 15	69	74	69	65	68	65
Jan. 5	71	74	....	74	70	([2])
Jan. 13	67	69	59	56	58	56
Jan. 19	56	58	53	54	53	56
Jan. 27	70	62	57	56	56	([2])

[1] Taken on morning following date given.
[2] Walking experiment in place of psychological measurements.

On the morning of December 20 arrangements were made for taking electrocardiograms of the men; hence the morning pulse-rate (No. 6 for December 19) was omitted. On the morning of February 3 with Squad A and of January 6 and 28 with Squad B the walking experiments on the treadmill were made; hence no pulse counts appear in the tables for No. 6 on February 2 and January 5 and 27. On all other days, six records were made. Although the pulse-rate for the sitting position would be expected to be somewhat higher than that for the

lying position, we have adhered to the procedure followed in table 80 of italicizing all pulse values between 40 and 36, inclusive, and giving in bold-face type the occasional records which are 35 or below. In interpreting the results of these pulse records in table 86 it should be borne in mind that all values were taken subsequent to the ingestion of food. As may be seen from the program for the day (see p. 59), the first count was approximately an hour after the standard restaurant supper eaten by the men on their visit to Boston. Counts Nos. 1 and 2 were made simultaneously by the entire squad. Counts Nos. 3, 4, 5, and 6 varied somewhat in time, as they were recorded in the intermission of the individual psychological tests which were given to the men in order during the evening and again on the following morning. Even with this variation in time, none of the subjects were in the post-absorptive condition and the influence of food ingestion as well as that of the sitting position must be recognized in comparing these pulse values with other series.

Noting first the course of the pulse values obtained by the subjects themselves in the first three counts of each evening, we find that the first count for Squad A (that for December 8) was made when the subjects had been for several weeks on reduced diet. On February 2 the pulse-rate was in most instances somewhat higher than on the other days, and the men were evidently more or less stimulated by the fact that this was the last session.

The pulse-rates on December 19 and January 12 and 26 were reasonably uniform, although the values for January 12 have a tendency to be higher than on either of the other days. No basal pulse counts were obtained under these conditions, either prior to the low diet or after normal diet was resumed. Values between 40 and 36 occur with 6 subjects and values of 35 or below with 3 subjects. The absolute minimum was observed with *Vea*, in count No. 5 on the evening of January 26, with a low value of 33. In general the pulse had a tendency to fall off as the evening progressed, the highest value appearing in count No. 1 and the lowest usually in count No. 5. The count taken the following morning usually shows values higher than the last count in the preceding evening. Only 2 pulse-rates of 40 appear in the No. 6 values. The difference between Nos. 5 and 6, or the last record of the evening and the first record of the morning, is, in the case of *Bro*, very slight. With the other subjects it is pronounced, showing on the whole a real difference in metabolic level. This may in part be ascribed to the fact that the pulse records in the morning were usually taken not long after breakfast and following the incidental activity of rising, leaving the respiration chamber, walking up a flight of stairs, dressing, eating breakfast, and going downstairs to the psychological laboratory, an activity which was as a rule considerably more marked than that preceding the counts on the evening before.

With Squad B we have certain values for comparison which may be taken as normal, *i. e.*, those for December 15 and January 5. In table 87 we have again adopted the arbitrary procedure of italicizing all values of 40 and below. The lowest absolute value found in any instance is 37 with *Liv* on the evening of January 27. Most of the italicized figures fall in count No. 5, a condition likewise observed in the case of Squad A.

In general, the normal values found on January 5 or prior thereto are not greatly altered on January 13 (the first session with reduced diet); the only striking exceptions to this uniformity are with *How* and *Sch*. It would thus appear that one week of reduced diet was not sufficient to affect greatly the pulse values for this squad when taken with the men in the sitting position and undergoing the moderate intellectual and physical activity of the psychological tests. On the other hand, an examination of all the data for January 19 and 27 shows almost invariably marked decreases in pulse-rate for all the counts. Thus we have a clear picture during the last two sessions of a decided influence of the reduced diet upon the sitting pulse taken under conditions of the psychological session at the Nutrition Laboratory.

Although as a rule the values in column 6 are greater than those in column 5, too many irregularities exist to permit of any definite deduction being drawn. The pronounced influence of the reduced diet shown in table 87, especially after the first week, is in complete harmony with the effect noted in tables 80 to 82 upon the resting pulse-rate taken with the men in both squads in the lying position. These sitting pulse-rates, which were influenced more or less by minor activity and particularly by food in the stomach, have by no means the significance of the basal morning pulse, but they serve to show that not only is the quiescent resting pulse profoundly affected by the dietetic règime, but that the sitting pulse following digestion is likewise affected. The fact that with Squad B this influence is hardly appreciable at the end of the first week of dieting is of significance when it is considered that these men were upon a diet representing approximately but one-third of their previous maintenance requirements. Pulse data of this character are especially helpful in suggesting the probability that the total heart action and metabolism are profoundly depressed by the low diet, not only during periods of complete muscular repose, but likewise under conditions of moderate intellectual and physical activity, complicated in part by digestive processes, although, owing to the extraordinarily reduced diet, it is hardly to be presumed that the influence of the ingestion of food is at all comparable to that existing under normal conditions.

PULSE RECORDS AT MEAL TIMES.

Through the kindness of Mr. Charles Wesley Davis, of the Y. M. C. A. College, we are permitted to use some pulse-rate data obtained

under his direction at the noon and evening meals with Squad A and with all three meals with Squad B. For this series of observations each man was instructed to count his own pulse once during the meal and record it on a tablet on the table. The counts were made from October 17 to the end of the research.

PULSE RECORDS AT MEAL TIMES, SQUAD A.

As an indication of the ordinary course of the pulse-rate counted under these conditions at the noon meal, we reproduce in table 88 a

TABLE 88.—*Individual pulse records at noon meal—Squad A.*

	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av.
Oct. 17....	.....	64	.....	54	72	66	80	50	70	66	92	86	70
18....	.....	70	[1]70	70	68	64	52	48	56	64	80	68	65
19....	76	56	[1]70	52	70	70	62	50	84	82	70	56	67
20....	.....	50	[1]58	54	64	60	54	48	58	54	84	56	58
21....	76	64	[1]68	56	84	62	58	60	50	74	88	84	69
22....	70	66	[1]64	68	66	64	52	48	42	64	72	48	60
23....	70	56	.....	48	66	66	48	46	60	58	68	52	58
24....	.....	70	[1]60	64	72	66	68	46	54	64	74	56	63
25....	.....	54	[1]64	48	72	64	52	46	48	62	68	48	57
26....	80	60	.....	48	72	62	54	50	54	80	72	56	63
27....	.....	56	.....	46	68	66	50	58	70	74	84	60	63
29[2]....	.....	56	.....	50	.....	64	.....	.....	48	.....	.....	52	54
30....	.....	.....	60	64	72	72	64	50	58	76	72	56	64
31....	60	56	48	52	68	60	58	56	52	56	66	60	58
Nov. 1....	.....	62	54	64	72	60	50	42	48	60	66	56	58
2....	84	46	54	48	66	62	62	48	46	66	68	56	59
3....	56	54	.....	52	72	66	60	48	50	52	60	60	57
4....	56	56	54	52	66	62	52	42	56	52	68	56	56
5....	72	68	50	64	62	64	48	44	58	62	60	60	59
6....	62	58	58	60	52	68	50	44	50	68	54	68	58
7....	52	.....	56	64	62	68	42	50	48	58	.....	60	56
8....	54	52	50	46	54	58	*40*	46	*40*	54	68	48	51
9....	58	54	54	56	.....	54	42	52	*38*	50	76	*40*	52
10....	78	50	50	52	60	56	48	.....	54	54	68	52	57
12[3]....	56	56	44	44	58	54	48	50	48	52	.....	56	51
13....	56	54	44	52	64	56	48	50	*40*	56	76	44	53
14....	52	54	46	58	58	66	44	56	50	72	68	48	56
15....	60	66	46	46	64	60	42	44	50	60	72	48	55
16....	64	50	44	42	62	60	56	46	*40*	78	64	44	54
17....	.....	56	46	50	66	66	52	.....	42	98	.....	52	59
18....	72	58	56	44	66	60	*40*	48	46	70	64	48	56
19....	56	52	46	52	58	60	44	46	*36*	72	68	48	53
20....	52	52	44	44	62	60	46	46	44	56	60	*40*	51
21....	58	50	*40*	52	64	54	42	50	**34**	54	56	*40*	50
22....	.....	62	*40*	42	54	50	*36*	42	*36*	54	70	48	49
23....	52	56	*40*	52	50	60	44	48	*38*	58	72	48	52
24....	60	62	*38*	*40*	52	66	**34**	38	**34**	54	48	*40*	47
26[4]....	68	62	42	([5])	76	60	44	52	48	76	.....	52	58
27....	68	62	*40*	([5])	64	62	*40*	42	44	60	64	48	54
28....	.....	.....	52	56	60	66	60	62	46	72	.....	48	58
29[6]....	46	56	56	.....	.....	64	46	46	62	60	88	52	58
30....	.....	56	56	44	56	62	56	46	60	56	80	44	56

[1] These records were obtained with *Fre* who left Squad A on Oct. 25.
[2] In Boston Oct. 28; no record taken.
[3] In Boston Nov. 11; no record taken.
[4] In Boston Nov. 25; no record taken.
[5] Ill with a cold.
[6] Thanksgiving Day; the men had full diet.

section from one of the tables in Mr. Davis's thesis. This shows the values obtained with Squad A at noon from October 17 to November 30. The counts were of course obtained with varying amounts of food in the stomach and after considerable conversation and minor movement, and they may also have been preceded by a somewhat brisk walk to the dining-hall. On the other hand, these irregularities are more or less eliminated in the averages for each day which are recorded at the extreme right in table 88. In considering these records, it should be noted that the actual number of men included in the averages varied but little from day to day. The tendency shown in the records from October 17 to November 30 is for the average pulse to fall somewhat. The absolute minimum average for the squad during this period is 47 on November 24, the average on this day representing the entire squad.

As a general index of the trend of the averages for the entire period of the test, we reproduce another table from Mr. Davis's thesis which gives average values for periods of approximately 2 weeks for the whole series of noon observations for each subject. (See table 89.)

TABLE 89.—*Average pulse records at noon meal—Squad A.*

Subject.	Oct. 17 to 31.	Nov. 1 to 15.	Nov. 16 to 30.	Dec. 5 to 19.	Jan. 7 to 20.	Jan. 21 to Feb. 2.
Bro	72	61	60	64	71	62
Can	60	56	57	57	60	56
Kon	[1]54	51	46	49	58	47
Gar	55	54	47	48	54	47
Gul	70	62	61	58	64	54
Mon	65	61	61	58	64	61
Moy	58	48	46	53	56	49
Pea	51	47	47	48	51	45
Pec	57	48	44	46	56	50
Spe	67	58	66	[2]63	....	....
Tom	76	67	67	63	[3]79	75
Vea	60	54	47	44	48	*39*
Average	62	56	54	54	60	53

[1] From Oct. 30 to 31. The average for *Fre*, whom he replaced, was 65 for Oct. 17 to 25.
[2] From Dec. 5 to 12.
[3] *Tom* had an operation during the Christmas vacation. See his personal history, page 52.

These averages indicate a fall to a level of 54 during the observations from November 16 to December 19. The high value from January 7 to 20 is due to the increase noted with all the men after the return from the Christmas vacation. The values for January 21 to February 2 are again at the lower level. None of the observations averaged in this table were obtained during full diet, save for the last two days in November.

As an illustration of the observations made at the evening meal, the records for October 17 to November 30 are reproduced in table 90,

TABLE 90.—*Individual pulse records at evening meal—Squad A.*

	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av.
Oct. 17....	.....	58	.....	60	.....	.....	.....	72	72	68	.....	72	67
18....	.....	52	[1]64	60	.....	74	58	58	.....	74	75	52	63
19....	.....	70	[1]76	50	78	66	68	50	72	70	76	62	67
20....	86	70	[1]62	60	72	60	66	68	60	70	92	60	69
22....	.....	64	[1]78	50	70	66	56	46	64	64	.....	60	62
23....	76	62	[1]80	54	66	66	54	54	48	82	74	56	64
24....	.....	60	[1]74	48	70	68	50	50	56	76	72	60	62
25....	.....	.....	[1]72	56	78	64	58	54	56	70	62	48	62
26....	.....	68	.....	46	74	62	68	56	64	92	74	56	66
27....	70	56	64	46	68	70	60	52	54	76	72	72	63
29[2]....	80	66	.....	60	.....	66	52	56	56	66	86	68	66
30....	76	68	54	44	72	56	68	48	48	60	66	56	60
31....	84	46	76	48	78	66	56	60	52	80	82	60	66
Nov. 1....	.....	56	70	64	78	80	82	46	52	60	64	56	64
2....	.....	50	54	50	72	52	60	50	46	74	80	60	59
3....	66	56	.....	54	58	56	46	56	58	52	60	48	55
5....	72	60	64	50	66	60	*40*	46	50	68	60	64	58
6....	72	54	54	56	60	80	44	*40*	50	62	60	60	58
7....	60	50	58	50	72	64	50	62	58	58	72	48	59
8....	.....	58	62	52	46	50	44	*40*	50	68	64	44	53
9....	64	64	48	50	.....	56	58	48	.....	60	76	52	58
10....	72	64	68	48	60	58	48	52	52	64	72	52	59
12[3]....	60	60	44	58	54	48	66	46	64	74	72	60	59
13....	58	58	48	46	60	56	44	48	48	70	64	48	54
14....	64	70	70	48	62	82	50	60	54	68	72	52	63
15....	72	72	50	56	52	60	60	50	76	52	72	48	60
16....	82	56	44	50	66	58	56	44	46	80	64	*40*	57
17....	64	60	48	42	60	52	46	56	46	90	64	48	56
19....	60	58	46	50	60	70	42	48	50	66	64	52	56
20....	62	50	68	52	62	66	*40*	48	46	76	68	44	57
21....	.....	62	46	48	68	64	.....	50	54	60	.....	44	55
22....	.....	54	46	50	68	66	.....	50	.....	80	76	48	60
23....	70	54	*40*	52	62	64	46	50	42	54	.....	48	53
24....	78	66	44	46	48	64	46	*40*	34	56	64	48	53
26[4]....	78	66	.....	.....	76	74	48	58	42	70	76	44	63
27....	72	.....	44	.....	64	70	52	48	44	74	.....	48	57
29[5]....	76	70	70	58	76	64	64	56	56	80	[6]104	56	69
30....	.....	52	52	50	72	62	68	44	42	54	80	48	57

[1] These records were obtained with *Fre* who left Squad A on Oct. 25.
[2] In Boston Oct. 28; no record taken.
[3] In Boston Nov. 11; no record taken.
[4] In Boston Nov. 25; no record taken.
[5] Thanksgiving Day; the men had full diet. No record for Nov. 28.
[6] Highest individual rate during entire test with Squad A.

in which the daily averages are likewise given at the extreme right. Here again a tendency is shown for the pulse-rate to fall as the study progressed, the absolute minimum for the entire squad (53 beats) being noted on three days, November 8, 23, and 24. An unusually high value was obtained on November 29, which was due in no small part to the extraordinarily high pulse-rate of *Tom* of 104, which was recorded as the highest individual pulse-rate noted for Squad A.

The averages for the successive periods of the observations for the evening meals are given in table 91 and show little, if any, positive change due to the diet. The level after the first period in table 91

TABLE 91.—*Average pulse records at evening meal—Squad A.*

Subject.	Oct. 17 to 31.	Nov. 1 to 15.	Nov. 16 to 30.	Dec. 5 to 19.	Jan. 7 to 20.	Jan. 21 to Feb. 2.
Bro	79	66	71	68	74	73
Can	62	59	59	60	63	62
Kon	65	58	50	51	59	44
Gar	53	49	50	50	61	53
Gul	73	62	65	62	69	60
Mon	65	62	65	67	71	69
Moy	60	53	51	52	60	56
Pea	56	50	49	49	57	49
Pec	59	55	46	50	57	52
Spe	73	64	70	71	....	....
Tom	76	68	74	70	85	73
Vea	60	53	47	45	47	43
Average	65	58	58	58	64	58

remains remarkably constant at 58. From January 7 to 20 this level rises to 64, but again falls to 58 in the last period of the observations. From tables 89 and 91, therefore, while something can be inferred regarding the influence of reduced diet upon the pulse-rate, evidently averages obtained in this way for long periods will not suffice for a clear analysis, and a better idea may be obtained from a graphic representation of the individual values. Such representation is given in figure 91, (p. 411) in which the curves for the lying and sitting values obtained with Squad A are compared with each other.

PULSE RECORDS AT MEAL TIMES, SQUAD B.

The pulse data taken at meal times for Squad B in this series have a significance not found with those for Squad A, as with the second squad the counts were made with both normal and low diet. It is unnecessary here to give in detail the individual measurements reported by Mr. Davis, but the differences between the pulse values during October, November, and December and those for the January period have a special interest, as those for the first three months were obtained under normal diet conditions, while most of those recorded in January were with the low diet. With Squad B pulse counts were made not only at the noon and night meals, but likewise during the morning meals, and hence a direct comparison may be made of the morning, noon and night values. This comparison is made in table 92. Inasmuch as the subjects were on normal diet until January 8, we find a reasonable uniformity in the values. The normal morning pulse-rate averaged 63, the noon pulse 72, and the night 68. With the beginning of the reduced diet, however, a noticeable fall in the pulse-rate is found with the entire group, and the three average values recorded beginning January 8 are on a definitely lower level than any of the earlier records. The average for the morning records during the low-diet period from January 8 to

TABLE 92.—*Average pulse records at morning, noon, and evening meals—Squad B.*[1]

	Morning.	Noon.	Night.		Morning.	Noon.	Night.
Oct. 19 to 31......	63	73	66	Jan. 1 to 7.........	62	70	66
Nov. 1 to 15......	63	74	68	Jan. 8 to 12........	[3]59	[3]65	[3]61
Nov. 16 to 30.....	63	72	68	Jan. 13 to 20.......	[3]57	[3]62	[3]57
Dec. 1 to 12.......	63	70	68	Jan. 21 to 28.......	[3]53	[3]57	[3]55
Dec. 13 to 19......	63	70	69	Jan. 29 to Feb. 2[4]..	64	70	72
Dec. 20 to 31[2].....	63	72	70				

[1] Only 8 men included in these averages.
[2] Records for only four men.
[3] With reduced diet.
[4] Records for only two men; unrestricted diet.

28 was 56 beats, or 7 beats lower than with full diet. The noon average with reduced diet was 61 beats, or 11 beats lower than with the normal diet. At night the rate was lower than at noon, being 68 on normal diet and 58 on restricted diet with a difference of 10 beats. With Squad A the reverse was found, the evening rate being higher than that recorded at noon. This may in part be explained by the fact that the members of Squad A took their physical exercise between 3^h30^m and 5 o'clock in the afternoon while most of the men in Squad B took theirs in the morning; hence the after-effect of muscular activity may have influenced the pulse-rates.

In the post-diet period we have observations for but two men. These show the characteristic rise in pulse-rate which is likewise observed with Squad A in the post-diet values obtained prior to bicycle riding. (See p. 397.) The general picture, therefore, presented by Squad B is in full conformity with that shown by Squad A and in addition we have a very clear picture of the normality of the pulse-rate taken under conditions obtaining in Mr. Davis's counts.

While these sitting pulse-rates of Squads A and B counted by the subjects themselves under considerable psychical, digestive, and slight muscular activity can not have the significance of careful records during complete repose, they contribute important confirmatory evidence as to the depressing effect of the reduced diet upon the heart rate.

PULSE CURVES FOR SQUAD A.

To give an indication of the general influence of the reduced diet upon the pulse-rate of the men in Squad A as observed in the series discussed in the previous sections, we have plotted the average values and give these curves in figure 91. The values plotted include: (1) the averages obtained for the basal pulse in the early morning, with the subject in the post-absorptive condition, without previous activity, and in the lying position; (2) the averages secured by Professor Johnson immediately before work with the subject in the lying position but not in the post-absorptive condition; (3) those obtained by the subjects on themselves in the sitting position at the noon meal, and (4) in the same position at the evening meal.

An examination of these curves shows that the basal pulse falls to a minimum about the middle of November, with a tendency thereafter to a slight rise to a somewhat higher level during December. On the return of the men from the Christmas vacation the pulse-rates begin at a higher level, with thereafter a distinct fall. The data obtained by Professor Johnson, which are plotted in the dotted line, follow with great regularity the course of the basal pulse obtained in the morning and show a reasonably constant difference in level between the two conditions under which the pulse was counted. The striking

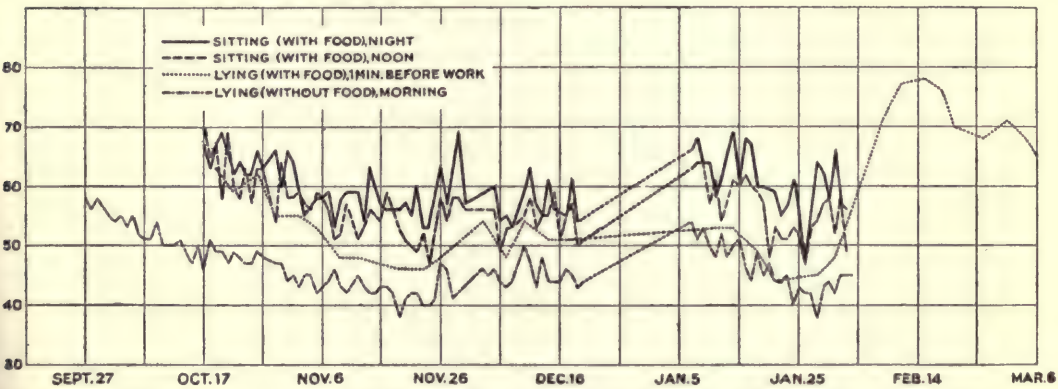

Fig. 91.—Pulse-rate curves for sitting and lying positions and at different times of day—Squad A.

increases in pulse-rate in the post-diet period are very clearly shown in this curve for Professor Johnson's data. The self-counts by the subjects at the noon and evening meals are very irregular, as would be expected. Both curves fall somewhat together in their general trend and approximate more or less the general form of the two lower curves for the values obtained in the early morning and prior to work. From an analysis of Mr. Davis's figures we find that the average pulse as shown for the counts made at the noon meal is 57, and that for the evening meal 60, thus showing a slightly higher pulse at night. This is borne out in general by the course of the two curves, although the irregularities and intersections of the two records are so great that it is difficult to draw any quantitative estimate from them. A general conclusion may be drawn, however, that the pulse-rate, under conditions of food in the stomach and moderate activity, undergoes a striking change with a reduction in diet which is in conformity with the basal values obtained with the subject in the lying position. It is to be regretted that more data were not obtained previous to the diet restriction and in the post-diet period, but the curves obtained show clearly that the diet restriction had a profound influence upon the pulse-rate of the entire group of 12 men.

PULSE-RATE WITH STANDING POSITION.

STANDING PULSE RECORDS IN EXPERIMENTS WITH PORTABLE RESPIRATION APPARATUS.

Any records of pulse-rate taken under uniform conditions in a given position are of value as evidence of the influence of reduced diet upon this factor. A number of respiration experiments were made with these men which were designed primarily to determine the basal metabolism with the subject in the standing position prior to a series of measurements of the energy transformations during walking. This led to the recording of a number of pulse-rates during this position with both squads. With Squad A these were recorded only on the last day of the observation, that is, on a restricted diet. With Squad B records were obtained on January 6 before the subjects had begun the low diet, and again on January 28, the last day of the greatly reduced diet. These pulse-rates are given for both squads in table 93.

On all these mornings the resting pulse was determined with the subject lying with minimum muscular activity in the group chamber before he rose. These values are also given for all the subjects in column *a* in table 93, for comparison with the standing pulse-rates. The figures, so far as Squad A is concerned, present no abnormalities and show low values similar to those noted on the respiration apparatus at Springfield on the two days preceding. (See table 80.) Values below 40 are found with 5 subjects in each squad.

The pulse measurements for the standing position in the experiments with the portable respiration apparatus, which in some cases were made several hours after the pulse measurements in the group chamber, are given in column *b* of table 93 and show increments for all of the subjects. The increments of the standing pulse over the lying pulse are given in column *c*. The greatest increment for Squad A is with *Can*, whose pulse rose from 48 to 84, *i. e.*, 36 beats. The smallest increments were noted with *Bro* and *Mon*, of 5 each. The average increment is 17, if we exclude the large increment of *Can* in averaging.

It is unnecessary for us to go to earlier literature for a base line or for comparisons, as data were obtained with Squad B on normal and on reduced diet and in both positions. These values are given in the lower part of table 93. Attention may first be called to the fact that the pulse-rates for January 28 were invariably lower than those for January 6, when the men were on normal diet. Especial emphasis must be laid upon the increments due to standing, which are recorded in column *c* of table 93. The highest increment on normal diet is with *Sne*, with an increment of 41 beats, *i.e.*, a rise from 48 to 89 beats. If we exclude this high value for *Sne* the average increment for Squad B with normal diet on January 6 would be 18. It thus appears that the increment due to change from the lying to the standing position was essentially the same on the reduced diet with Squad A as with that on

TABLE 93.—*Comparison of pulse-rates of subjects in lying and standing positions, subjects without food from 11 to 19 hours.*[1]

Diet and dates.	Squad and subject.	(a) Lying in group respiration chamber.	(b) Standing at portable respiration apparatus.	(c) Increase over lying (b-a).	(d) Standing before walking.	Remarks.
Reduced:	*Squad A.*					
Feb. 3, 1918.	Bro......	56	61	5	66	Pulse-rates lying taken between 4 and 5 a. m., except for Bro, Kon, and Mon, whose records were obtained as late as 6 a. m.
	Can......	48	84	[2]36	[3]74	
	Kon.....	39	56	17	....	
	Gar......	36	46	10	44	
	Gul......	48	73	25	69	
	Mon.....	55	60	5	58	
	Moy.....	45	60	15	....	
	Pea......	38	59	21	....	
	Pec......	37	59	22	54	
	Tom.....	60	88	28	80	
	Vea......	35	54	19	....	
Average...	....	45	64	[2]17	64	
Normal:	*Squad B.*					
Jan. 6, 1918[4].	Fis......	56	74	18	82	Pulse-rates lying taken between 4 and 5 a. m.
	Har......	60	78	18	79	
	How.....	58	....	....	77	
	Ham.....	63	80	17	95	
	Kim.....	59	83	24	80	
	Sch......	45	69	24	68	
	Liv......	60	68	8	71	
	Sne......	48	89	[2]41	69	
	Tho......	54	71	17	77	
	Van......	54	72	18	....	
	Wil......	57	72	15	83	
Average...	....	56	76	[2]18	78	
Reduced:	*Squad B.*					
Jan. 28, 1918[5]	Fis.......	39	66	27	55	Pulse-rates lying taken about 4^h30^m a. m.
	Har......	44	65	21	....	
	How.....	40	....	....	....	
	Ham.....	42	67	25	55	
	Kim.....	48	71	23	60	
	Sch......	33	51	18	....	
	Liv......	39	53	14	43	
	Sne......	40	71	[2]31	[3]67	
	Tho......	39	55	16	51	
	Van......	34	50	16	46	
	Wil......	47	56	9	....	
Average...	....	40	61	[2]19	54	

[1] The time when the pulse was observed for the standing position varied according to the order in which subjects were used.

[2] Increase over lying for *Can* and *Sne* omitted from averages.

[3] The value of 74 for *Can* is an average of 81 (standing outside chamber) and 67 (standing on treadmill in chamber); likewise 67 for *Sne* is an average of 72 and 62.

[4] *McM*, Jan. 6; pulse-rate, lying, 63; standing at portable, 80; increase over lying, 17; standing before walking, 84.

[5] *Lon*, Jan. 28; pulse-rate, lying, 35; standing at portable, 52; increase over lying, 17.

normal diet with Squad B. The increments on reduced diet with Squad B (see January 28) range from 31 with *Sne*, who likewise showed the highest increment on normal diet, to 9 with *Wil*. Excluding *Sne*, we find the average increment on reduced diet to be somewhat less than 20, which is in full conformity with that noted for Squad A.

Although the abnormally high increases for *Can* on February 3 and for *Sne* on January 6 and January 28 were eliminated from the averages, and the average increment for the standing position remains essentially the same on all three days, namely, 17, 18, and 19 beats, it can be seen that including these men in the average would but slightly alter the differences between these increases, and the increment due to change in position from lying to standing was practically the same under normal conditions and with reduced diet conditions. The normal values in this case are, however, represented by only one day (January 6) and the reduced diet by two days (January 28 and February 3) with different squads. Special attention should be called to the low averages for the basal pulse on the reduced diet days, these being 45 for Squad A and 40 for Squad B.

These increases are expressed in actual pulse beats, but it should be noted that the *percentage increase* is very considerably greater during the restricted diet than with the normal diet. Thus with Squad A the increase of 17 beats on February 3 with the basal value of 45 represents a percentage increase of 37.8 per cent. With Squad B on reduced diet (January 28), the increase of 19 on a basal value of 40 represents 47.5 per cent, while with Squad B on normal diet (January 6) the increase of 18 on a basal value of 56 represents 32.1 per cent increase, a materially lower figure.

In general, it can be seen that a change in position from lying in the group respiration chamber to standing with the portable respiration apparatus leads to an increase in pulse-rate of not far from 18 beats, an increment which is slightly greater in absolute terms and considerably greater in percentages with reduced diet than with normal diet. These differences, however, are not to be confused with the absolute height of the pulse-rate, which is much lower on the reduced days than on the normal days, this being shown more clearly with Squad B than with Squad A.

STANDING PULSE RECORDS PREVIOUS TO TREADMILL EXPERIMENTS.

A still further record of pulse-rate for the standing position was obtained just prior to the walking experiments, when the subject was standing outside the chamber or on the treadmill prior to the actual walking test. Although these pulse-rates, which were recorded by the string galvanometer method, have a greater significance in indicating the transition pulse from standing to walking and the reverse and will be considered later in connection with the pulse-rate obtained during walking, they are also perfectly comparable with the other

records for this position obtained in connection with the portable respiration apparatus. These values, which are entered in column *d* of table 93, are more irregular than the others in that they were not secured for all the men. As a matter of fact, the average values found with the squads by the two methods are strikingly uniform on February 3 and January 6, but on January 28 an average pulse-rate of 61 was secured in the standing experiments with the portable respiration apparatus, as compared with an average of 54 for the standing values obtained before the walking experiment. Somewhat wide variations are noted in individual cases, particularly with *Ham* on January 6, when the pulse-rate standing with the portable apparatus was 80 and just prior to walking on the treadmill was 95, and with *Sne* on the same day with pulse-rates of 89 and 69.

While the increment due to standing over lying is practically the same, both with the normal diet and with the reduced diet, a much lower pulse-rate prevails with Squad B on the reduced diet than with the normal diet. In other words, the general depressing effect on the heart action of the reduced diet obtains even with the moderate strain of the standing position prior to walking.

In footnotes with table 93 values are recorded which were obtained with *McM* on the normal diet day (January 6) and for *Lon* on the day with reduced diet (January 28). It is perhaps of significance that the increment due to standing over lying is with these two men the average of practically all the others. The standing values with *McM* were obtained under both conditions and agree fairly well, the values being 80 and 84, respectively. They represent, however, distinctly fragmentary evidence and are not included in the general averages.

CHANGES IN PULSE-RATE OCCASIONED BY SHORT PERIODS OF EXERTION.

The ability for adaptive increase in heart rate following exercise is of prime importance to the organism. In normal persons the circulation adjusts itself very rapidly to the muscular demand. The cardio-inhibitory center is very sensitive. Investigators have observed that with subjects sitting quietly the pulse-rate changes in the next one or two cycles following the movement of the arm or any slight change in the bodily position. The quickness with which the change occurs from the resting pulse to the rate for exercise, provided the exercise begins promptly, is a measure of vagus tone. In certain physiological conditions, notably that of heart block, the adaptive increase in heart rate during exercise will not take place. It is stated by Wiggers[1] that this is even more characteristic of incomplete heart block.

Since it therefore happens that with many individuals showing a slow radial pulse-rate, the circulation is adequate for conditions of muscular repose but decidedly inefficient during exertion, and since

[1] Wiggers, Circulation in health and disease, Philadelphia, 1915, p. 279.

the subjects in the low-diet research began somewhat early to exhibit radial pulse-rates which were notably below those of normal, it appeared to us particularly important to examine the change in heart rate with exertion. An accurate and at the same time the most convenient method of securing records which will provide information of this sort is to take electrocardiograms by the technique described on page 152, *i. e.*, with body electrodes connecting the subject to the string galvanometer for the taking of continuous records while he is quiet, active, and again at rest. The sample records, which are illustrated in figure 24 (see page 152), demonstrate clearly that any considerable irregularity in the rhythm or conduction of the electrocardiogram under these conditions could be readily discovered, except perhaps during the actual moments of exertion, when only the prominent R deflection is legible in the tracing. The auricular wave P is usually very small, partly because of the capacity and resistance in series in the circuit reducing the amplitude of the deflections. The P wave is, however, usually indicated in the quiet pulse prior to exertion. It also becomes visible in the latter part of the recuperation period, and since the ventricular complex (R and T waves) appears with increased frequency between the two points in the record where the P wave is not evident, it is probable that all of the impulses are of sinus origin and proceed in the normal way. No stress can be laid upon the shape of the waves. Only their order and frequency concern us here.

To secure an accurate measure of the length of the pulse cycle, we measured from the sharp point R to R.[1] A table for all the pulse-cycle data shown n these records would be very large and unwieldy. Data of this character for a series of similar electrocardiograms taken on one subject have been published elsewhere.[2] Each individual pulse cycle (R to R distance) is measured, the unit being 0.01 second. In discussing such pulse changes, it is more logical to use pulse-cycle length than pulse-rate per minute. The two statements must not be confused. The data can be conveniently presented in the form of curves. An illustrative set of curves for an individual subject is given in figure 92. Records were taken for *Mon* on the five days, October 28, November 11, December 9, January 13, and January 27. In order to avoid a confused diagram, curves for only three dates are given, those for November 11, December 9, and January 27. In each case the curve is the average for two similar and consecutive records, separated by one minute or more of rest. The portion of the curve to the left of the heavy vertical line represents the period of quiet rest in the steamer chair. The pulse-cycle length varies somewhat, as is to be expected in any normal individual, due to the respiratory changes and other influences on the vagus. No signal or indication was given to the subject

[1] Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 95.
[2] Miles, *ibid.*, p. 98, table 17.

until the exact moment when he was to grasp the bar and "chin" himself, the beginning of which event is represented by the vertical heavy line. Immediately at the beginning of exercise the cycle length is shortened and continues to decrease during the 5 seconds of muscular tension, the end of which is indicated in each curve by a short vertical line.

The curve for December 9 in figure 92 is at a higher level—*i. e.*, a faster pu se-rate—particularly in the period of quiet and of rest. It is also to be observed in the case of this curve that at the end of the exertion the pulse continues to rise during about 5 cycles, after which it shows

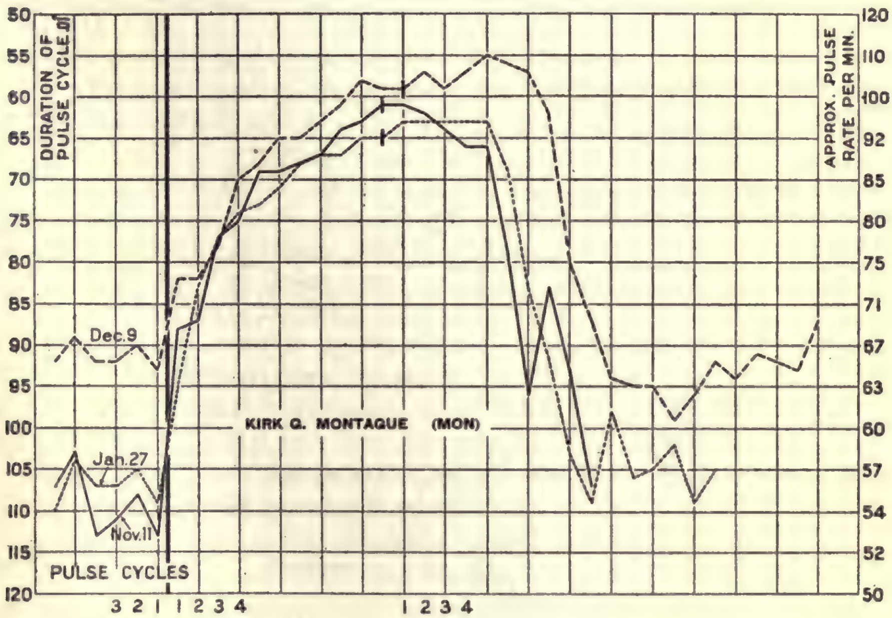

Fig. 92.—Changes in the pulse-cycle duration with exertion, Kirk G. Montague.

The portion of the curves to the left of the heavy vertical line represents the pulse cycles during quiet. Between the heavy vertical line and the short lines through the curves is the period of exertion. The portion at the right of the short verticals is for the period of recuperation.

a steep decline. December 9 was not long after the Thanksgiving vacation, and the pulse-rate had risen on this date to more nearly its normal level. On November 11 and January 27 the reduced diet had been in force for several weeks continuously in each case and the pulse was at a lower level. The difference in level between December 9 and the other two dates is particularly prominent in the quiet pulse, that is, preceding the activity. It is less prominent in the rest pulse following the activity and rather slight during the activity. It is significant that the cycle length during exercise is so nearly the same, even though the resting pulse is at rather widely different levels. It would appear that

in the case of this individual the given amount of exercise required a pulse-rate of about a certain level, and that in the case of the lower resting rate the tone of the vagus is higher or is somewhat more affected at the time of the exercise.

Different subjects show, naturally, individual peculiarities in their curves for changes in pulse-cycle length during and following the short periods of exertion but, in general, the pulse-cycle length required for the exercise tends with any individual to be a constant, no matter what the resting level may be.[1]

It is rather difficult to place the data for these pulse changes in quantitative terms for comparison. An effort in this direction is made in tables 94 and 95 for Squads A and B, respectively. The three figures given for any subject and date represent the average pulse-cycle length in 0.01 second in the three different portions of the record. For example, with *Bro* on October 28, 0.92″ is the average pulse-cycle length of the 6 pulse cycles in the portion of the record which preceded the beginning of activity, 0.66″ is the average for all of the pulse cycles which came within the limits of the activity, and 0.67″ the average of the 20 pulse cycles which followed the cessation of activity. (See table 94.) With each subject these same conditions for the averages apply. All the members of Squad A, excluding *Kon* and *Spe*,[2] show averages for October 28 of 103 for the period of quiet, 75 for the period of activity, and 79 for the first 20 pulse cycles in recuperation following activity. Assuming the duration of pulse cycles during "quiet" as a basis for calculation, we have for activity and rest 72.8 and 76.6 per cent, respectively, as shown in the extreme right-hand column of the table. Therefore the average cycle-length during the period of activity was 27.2 per cent shorter than during the quiet, and in the 20 beats following the activity it was still on the average 23.4 per cent shorter than during the period of quiet.[3]

The low diet average for Squad A for the 5 dates, October 28, November 11, December 9, January 13, and January 27, and for the 10 men whose records were averaged (*Kon* and *Spe* omitted) are 109, 77, and 85 for quiet, activity, and rest, respectively. The activity and rest are but 70.6 and 78.0 per cent of the quiet pulse-cycle length. The individual subjects show an average pulse-cycle length under conditions of quiet which ranges from 87 to 125—*Tom* and *Pea*. Two other subjects, *Vea* and *Pec*, are very close to this upper value; that is, they

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[1] Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 102 ff.; see figs. 12, 13, and 14. This was found to be the case, also, when a subject was under the influence of small amounts of alcohol.

[2] *Kon* came into Squad A late and *Spe* was ill after December. These two subjects were omitted from the averages in the neuro-muscular measurements. See p. 557.

[3] While a shorter pulse-cycle length means a faster rate per minute, the quantitative statement for change in the one can not be directly transferred to the other. The average cycle lengths, 103, 75, and 79, in terms of rate would equal 58, 80, and 76, respectively. The activity and rest sections therefore show increments of 22 and 18 beats per minute over the quiet, which was 58. These changes in terms of rate are 38 and 31 per cent as compared to the 27.2 and 23.4 per cent for changes in cycle length.

Table 94.—*Different levels of pulse-cycle length with conditions of quiet, activity, and rest for the men of Squad A.*

[Values in 0.01 second for pulse-cycle length.]

Experiment and condition.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av.	P.ct.
Oct. 28 Quiet....	92	112	109	113	79	97	103	137	100	91	83	109	103	100
Active...	66	94	93	69	60	65	76	93	82	67	67	81	75	72.8
Rest....	67	78	91	70	67	85	84	98	87	65	68	82	79	76.6
Nov. 11 Quiet....	96	104	126	121	73	99	133	136	150	112	90	117	112	100
Active...	69	70	76	71	66	70	90	93	86	69	64	100	78	69.6
Rest.....	72	80	79	74	73	80	95	108	95	82	72	97	85	75.8
Dec. 9 Quiet....	93	114	112	117	.....	91	123	124	.....	108	86	127	109	100
Active...	68	63	71	72	.....	68	76	85	.....	70	64	96	74	67.9
Rest.....	67	91	73	84	.....	80	92	101	.....	71	64	98	85	78.0
Jan. 13 Quiet....	92	90	101	95	100	90	109	108	105	.....	([1])	127	102	100
Active...	73	66	67	67	73	71	79	77	84	.....	.....	93	76	74.5
Rest.....	77	80	70	68	86	84	84	89	84	.....	.....	95	83	81.4
Jan. 27 Quiet....	112	111	126	147	112	107	125	120	141	.....	88	138	120	100
Active...	84	74	79	87	71	73	88	91	97	.....	65	103	83	69.2
Rest.....	84	82	84	92	89	105	100	101	105	.....	64	108	93	77.5
Low-diet average:														
Quiet	97	106	115	119	91	97	119	125	124	104	87	124	109	100
Active	72	73	77	73	68	68	82	88	87	69	65	95	77	70.6
Rest.........	73	82	79	78	79	87	91	99	93	73	67	96	85	78.0
P. ct. change:														
Active	74.2	68.9	67.0	61.4	74.7	70.1	68.9	70.4	70.2	66.3	74.7	76.6	70.6	.....
Rest.........	75.3	77.4	68.7	65.6	86.8	89.6	76.4	79.2	75.0	70.2	77.0	77.4	78.0	.....

[1] On account of the operation which *Tom* had in early January he was not asked to do the chinning on this date.

each have 124 for pulse-cycle length corresponding with a rate per minute of 48 beats. The pulse-cycle length during activity shows a range from 65 to 95 for *Tom* and *Vea*, respectively. It is worthy of note that *Vea*, whose pulse has been spoken of in other connections (see p. 387) as so remarkably low, showed a cycle-length during activity considerably longer than that of *Pec* and *Pea*, whose quiet pulse length was at the same level with *Vea*. On the other hand, *Pea* and *Pec* show greater changes between activity and the subsequent rest than does *Vea*. The resting level ranges from 67 to 99 for *Tom* and *Pea*, respectively. In terms of per cent the activity is from 61.4 to 76.6 (*Gar* and *Vea*) of the quiet pulse-cycle length and the resting percentage is from 65.6 to 89.6 with *Gar* and *Mon*, the latter demonstrating unusally quick recovery in pulse-cycle length following the activity.

For Squad B records were taken on two normal dates, November 18 and December 16, and on two of the low-diet dates, January 14 and January 20. (See table 95.) The averages at the right-hand of the table do not include the values for *McM*, *Kim*, and *Sch*. The other 10 men show averages for November 18 of 94, 67, and 70, for conditions of quiet, activity, and rest, respectively. In per cent of the pulse-cycle length during quiet, the activity and rest are 71.3 and 74.2, respectively. The average pulse-cycle length for the two nor-

TABLE 95.—*Different levels of pulse-cycle length with conditions of quiet, activity, and rest for men of Squad B.*
[Values in 0.01 second for pulse-cycle length.]

Experiment and condition.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.	P. ct.
Normal:															
Nov. 18 Quiet..	101	93	68	82	82	.....	108	.....	99	84	112	98	96	94	100
Active.	74	68	58	61	67	.....	81	.....	73	58	69	61	71	67	71.3
Rest...	73	68	59	69	63	.....	75	.....	69	70	76	74	64	70	74.5
Dec. 16 Quiet..	.....	91	67	.....	88	.....	108	60	101	83	.....	93	90	90	100
Active.	.....	70	57	.....	67	.....	79	51	72	58	.....	63	71	67	74.4
Rest...	.....	72	56	.....	76	.....	81	54	68	66	.....	76	69	70	77.8
Normal average:															
Quiet........	101	92	68	82	.....	.....	108	.....	100	84	112	96	93	92	100
Active........	74	69	58	61	.....	.....	80	.....	73	58	69	62	71	67	72.8
Rest.........	73	70	58	69	.....	.....	78	.....	69	68	76	75	67	70	76.1
Per cent change:															
Active.......	73.3	75.0	85.3	74.4	.....	.....	84.0	.....	73.0	69.0	61.6	64.6	76.3	72.8	.....
Rest.........	72.3	76.0	85.3	84.2	.....	.....	72.1	.....	69.0	81.0	67.8	78.1	72.0	76.1	.....
Low-diet:															
Jan. 14 Quiet...	104	98	81	91	.....	97	109	105	118	80	130	122	103	104	100
Active.	75	78	59	65	.....	71	85	68	79	59	98	72	78	75	72.1
Rest...	76	67	55	62	.....	80	72	72	89	57	95	85	72	73	70.2
Jan. 20 Quiet..	105	115	87	89	.....	93	103	136	115	100	115	113	101	104	100
Active.	75	77	78	73	.....	73	86	83	74	67	80	67	78	76	73.1
Rest...	79	83	72	76	.....	76	82	90	79	66	95	89	81	80	76.9
Low-diet av'g:															
Quiet.........	105	107	84	90	.....	95	106	121	117	90	123	118	102	104	100
Active.......	75	78	69	69	.....	72	86	76	77	62	89	70	78	76	73.1
Rest.........	78	75	64	69	.....	78	77	81	84	62	95	87	77	77	74.0
Per cent change:															
Active.......	71.4	72.9	82.2	76.6	.....	75.8	81.2	62.9	65.8	70.0	69.5	59.3	76.4	73.0	.....
Rest.........	74.3	70.1	76.2	76.6	.....	82.1	72.6	67.0	71.8	68.9	74.2	73.7	75.4	74.0	.....

mal dates and for the three conditions in the records, as shown in the right-hand column of table 95, are 92, 67 and 70, the latter two values being 72.8 and 76.1 per cent, respectively, of the pulse-cycle length during quiet. The individual subjects show no marked peculiarity, except in the comparison of the pulse-cycle lengths for activity and rest. During the 20 beats in the rest following the activity five of the subjects, *Fis*, *How*, *Lon*, *Liv*, and *Wil*, have pulse-cycles as short as or shorter than during the activity. In other words, after the activity the pulse tended to remain high for a period. Thus we have a difference between the conditions of activity and rest (72.8 and 76.1) of only 3.3 per cent in the case of Squad B, while with Squad A the resting pulse-cycle length was 7.4 per cent longer than the cycle length during activity. In the average for the two low-diet experiments, several Squad B men show the same condition, that is, a faster pulse following the activity. Hence it can not be assumed that the contrast between the normal of Squad B and the records of Squad A is due to the reduced diet.

The average quiet, activity, and rest values with the percentage of change from the quiet as shown by activity and rest are, for com-

parison, summarized in table 96. In this are embodied, also, the results of normal series of 1917. Records, usually two for each man, obtained with 63 normal aviation candidates enter into this 1917 series. The technique employed with these men was identical with that used in this investigation and described on page 151, except that the first trial was not a practice trial without a record, as in the low-diet investigation, but with the aviators a record was taken. Thus the pulse-rate in the first record for the aviators was affected somewhat by the factor of excitation and novelty. It is possible that this in large part accounts for the difference between their average of 83 for the quiet pulse-cycle length and 92 for the normal average of the same measurement with Squad B, and likewise for the fact that the activity and rest values, 60 and 65, are shorter than the normal values of Squad B, *i. e.*, 67 and 70. However, both the normal values for Squad B and

TABLE 96.—*Summary for pulse changes occasioned by short periods of exertion.*

[Values in 0.01 second for pulse-cycle length.]

Groups of subjects and conditions compared.	Quiet.	Activity.	Rest.	Activity, p. ct. of change.	Rest, p. ct. of change.
Squad A, low-diet........	109	77	85	29	22
Squad B, normal.........	92	67	70	27	25
Squad B, low-diet........	104	76	77	27	26
Normal series of 1917.....	83	60	65	27	21

those in the series of 1917 definitely show shorter pulse-cycle lengths than the values for the low-diet period of Squad B and those of Squad A. Compared on the basis of percentage of change of the activity over the pulse-cycle length during quiet, we have for Squad A 29 per cent and for all the others 27 per cent—surely a remarkably close correspondence. The percentage of change in the 20 pulse-cycles following activity, as compared to the quiet pulse-cycle length, is for Squad A 22 per cent, while that for the normal series of 1917 is 21 per cent. With Squad B, also, the low-diet value is 1 per cent larger than the normal, being 26 per cent as compared with 25 per cent. As was mentioned earlier, certain of the members of Squad B demonstrated individual peculiarities, having a faster pulse than would normally be expected after activity.

Finally, we may compare the composite curves, which show not simply the levels in the three different conditions, quiet, activity, and rest, as presented and discussed in tables 94, 95, and 96, but also demonstrate the transitions and the progressive changes between these. An average was made for the comparable pulse-cycles of the 10 subjects of Squad A for three of the dates on which such tracings were taken for these men.[1] The average values obtained for these dates, to-

[1] We have omitted from the average the records of *Kon* and *Spe*.

gether with a similar average obtained for all of the records of the 63 men of the series of 1917, are plotted in curves and embodied in figure 93. A similar series of curves for Squad B, together with the average for the series of 1917, are presented in figure 94. As explained on page 416, two records, such as are illustrated in figure 24, were taken for each subject and date; therefore, as 10 subjects are averaged, each plotting-point is usually the average length of 20 pulse-cycles. The 6 pulse-cycles immediately preceding the beginning of activity were used

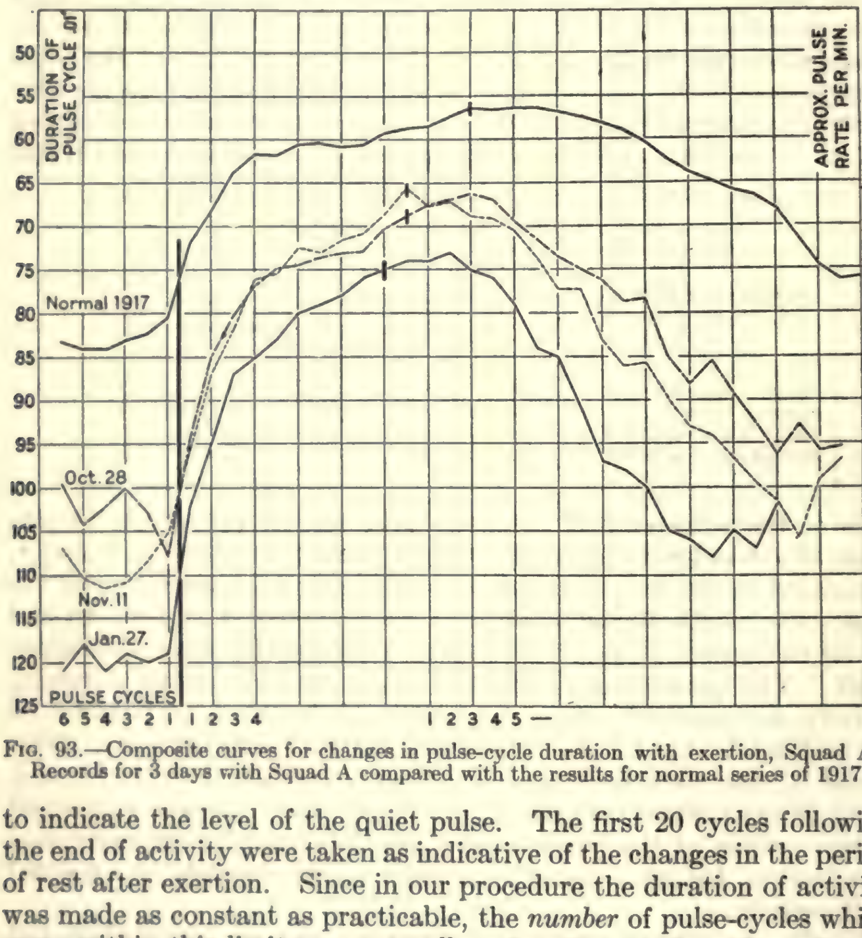

Fig. 93.—Composite curves for changes in pulse-cycle duration with exertion, Squad A—Records for 3 days with Squad A compared with the results for normal series of 1917.

to indicate the level of the quiet pulse. The first 20 cycles following the end of activity were taken as indicative of the changes in the period of rest after exertion. Since in our procedure the duration of activity was made as constant as practicable, the *number* of pulse-cycles which came within this limit was naturally a function of the pulse-rate and varied with different subjects. This, unfortunately, when one averages the records, causes an irregularity at the point of transition from activity to rest. In figure 93 the curves for Squad A show an irregular rise at this point due to the predominating influence of these faster pulse-rates. (See *Gul* and *Tom*, table 94.)

In all of the curves for Squads A and B, the major portion of the period of activity and also of the period of subsequent rest have a very

great uniformity, that is, the averages make very smooth curves. There is apparently no significant difference with Squads A, B, and the normal series of 1917 in the sharpness of the rise with beginning activity. The absolute change in hundredths of a second between the level for quiet and the level for activity is of course greater in those cases in which the level for quiet is low, as for example, on January 27 with Squad A (fig. 93), but, as we have seen previously, the percentage of change is about the same in each case. The irregularity at the beginning during the period of quiet is somewhat larger than would be expected, judging from the curve for the series of 1917. These irregularities, considered on the percentage basis, would not be as relatively

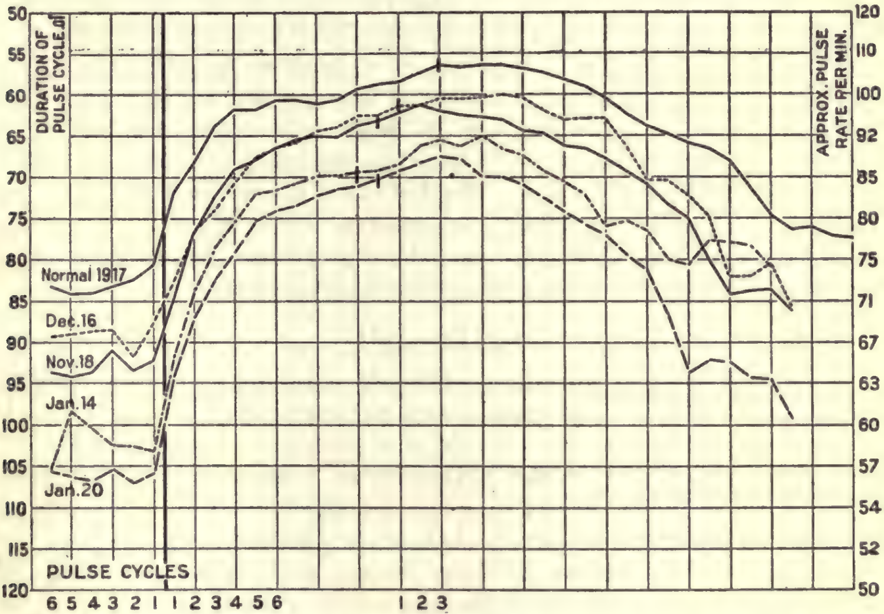

FIG. 94.—Composite curves for changes in pulse-cycle duration with exertion, Squad B—Records for 4 days with Squad B compared with the results for normal series of 1917.

large as they appear in the figure. It seems probable that at the lower pulse-rate the natural arrhythmia is accentuated. The descending portion of the curves is usually consistent in its uniformity until it reaches approximately the sixteenth pulse-cycle. Subsequently there is considerable fluctuation. From figure 93 it would appear that the return in the direction of the basal level for quiet is more prompt for Squad A than in the case of the normal series for 1917. If one had only these data it might be taken as an indication of a different condition due to the lower pulse-rate during the reduced diet. When we compare the curves for Squad B, however (see fig. 94), we find no sensible difference in their slope as compared with the normal series of 1917, and the normal curves of Squad B compare very favorably with those taken during the period of reduced diet.

The electrocardiograms taken to show the changes in heart rate due to short periods of general muscular exertion fail to demonstrate any pathological conditions, judged in the light of the available standards with which we may compare such records. No subject ever complained in connection with the test or asked to be excused or indicated any fatigue following the exercise. The only consistent difference exhibited between the men on reduced diet and those with uncontrolled diet is in the pulse-rate level, irrespective of whether we compare periods of quiet when the subject is relaxed, periods of exertion when the larger part of the voluntary musculature is under tension, or periods of rest following such activity. The percentage of rise in the pulse-rate occasioned by such activity, which is found on the average in the 20 pulse-cycles immediately following the activity, shows no significant change with reduced diet. It therefore appears certain that the lower nutritional level produced by continued low diet did not interfere with the ability for adaptive increase in heart rate under conditions of muscular exertion, when the needs of the organism naturally required an increase in the circulation. Furthermore, it may be stated that no annoying cardiac or respiratory symptoms, other than the described normal changes, followed these periods of exertion. In all the records there were no cases of extra systoles or skipped beats.

TRANSITION PULSE.

At the time of the treadmill experiments of January 28 and February 3, described on page 440, continuous electrocardiograms were taken on each subject during 15 seconds of standing and the immediately succeeding 60 seconds at the beginning of walking, and then again during the last 15 seconds of walking and the following 30 seconds of standing. The data thus obtained show the changes in duration of the pulse cycles as the pulse-rate alters during the successive seconds of walking or of standing. They also show how quickly the heart reacts to the stimulus and at which cycle the pulse has reached its maximum rate. We have termed these measurements the *transition pulse* as they were taken during the time that the heart was adjusting itself to the altered demands made upon it by the changed conditions of either walking or standing.

These measurements can best be presented graphically. Figures 95, 96, and 97 give the curves representing the transition pulse of the individual members of Squad B on January 28, 1918, and figures 98, 99, and 100 show those for Squad A on February 3, 1918. Since the measurements of the transition pulse were first made on January 28, there are no basal data for any of these subjects, *i.e.*, no data taken when the men were living on a normal diet. To supply this lack of basal material, five members of the Laboratory staff went through the walking routine in the post-absorptive condition during the week of

February 14 to 19, 1918, records being made of their transition pulse. The curves for these normal subjects appear in figure 101. In these figures the durations of the pulse cycles, calculated in 0.01 seconds, appear as ordinates. The abscissæ show the number of pulse cycles. The curves have been drawn so that each plotted point represents the average of two cycles, thus diminishing the small variations present in the normal heart action and producing a smoother curve. The heavy lines X and Y indicate the moment of transition from standing to walking and the reverse. The pulse cycles to the left of X represent the preliminary standing period. Those to the right of X represent the initial walking period. Similarly, the cycles to the left of Y are for walking and those to the right of Y are for standing. Between these two transition curves, there has also been inserted a short curve representing the pulse-rate at the sixth, twelfth, and twenty-fourth minutes of walking. Thus there are shown for each subject (1) the curve for the walking transition following standing; (2) the curve for the standing transition following walking; and (3) a curve for the pulse-rate at three points, usually after 6, 12, and 24 minutes of walking. The approximate pulse-rate corresponding to the length of pulse cycle is given on the right of the figure. Intervals of approximately 15 seconds are shown by the smaller figures at the bottom of each transition curve. The sixth, twelfth, and twenty-fourth minutes are also indicated on this line for the intervening walking curve, but it should be clearly understood that the times between these points, as represented by the abscissæ, are not uniform. For instance, with *Fis*, the time covered by the preliminary standing pulse record was 14.3 seconds. The first twenty cycles of walking lasted 15.4 seconds, while the entire walking portion of this transition record was 59.7 seconds. There is then an interval of slightly over 5 minutes before the pulse-rate for the sixth minute, and intervals of 6 and 12 minutes between the next two points. After the twenty-fourth minute, there is an elapsed period of approximately 2 minutes before standing began at Y. The ten pulse cycles of walking preceding the standing lasted 9.2 seconds, while the standing record was 28.6 seconds.

TRANSITION PULSE, SQUAD B.

It is hardly necessary to analyze each individual curve shown in the succeeding figures. The chief points of resemblance and difference can be brought out by considering a few curves from each group. In the pulse of *Fis* shown in figure 95, the average length of the first two pulse cycles noted was 1.16 seconds. The average of the next two pulse cycles was 1.10 seconds, after which the duration changed to 1.22 seconds for the average of the fifth and sixth cycles. From this point the duration of the pulse cycles shortened, and at the transition, X, the length was 0.99 second. The shortening of the duration of the

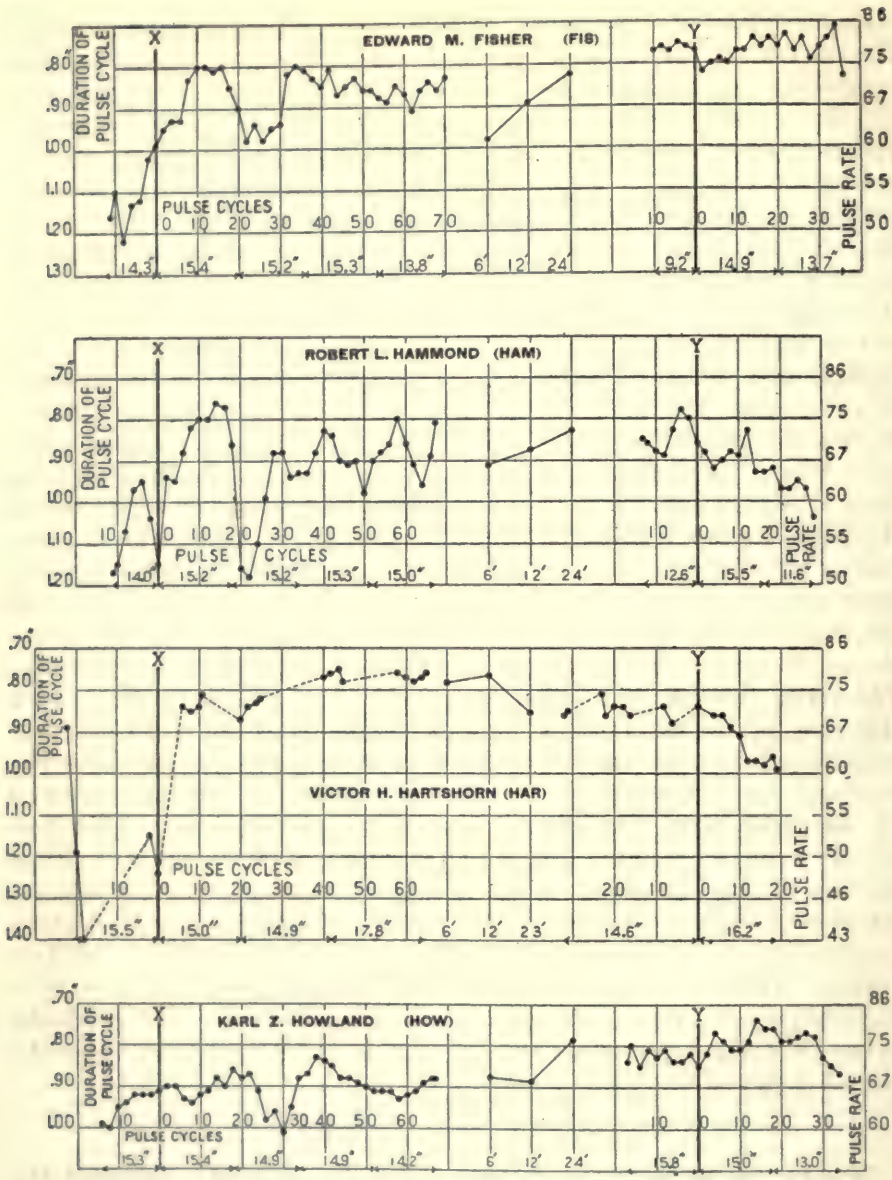

FIG. 95.—Transition pulse curves for Fisher, Hammond, Hartshorn, and Howland, Squad B, January 28, 1918.

The curves show the changes in the duration of the pulse cycles at the transition from standing to walking and also from walking to standing. X, transition point, standing-walking; Y, transition point, walking-standing. Duration of pulse cycle is given in 0.01″. Each plotted point is the average of two cycles. The equivalent pulse-rate per minute is shown at the right. The elapsed time is given in seconds in smaller type at the bottom. The pulse-rates at the sixth, twelfth, and twenty-fourth minutes of walking are inserted between the two transition curves and indicate the pulse-rates as the walking progressed.

cycle continued until the tenth cycle after walking started, which was 0.80 second; it then remained practically constant through the sixteenth beat, after which the duration began to lengthen again and continued lengthening until the twenty-second cycle. There followed, then, a period of some slight variations up to the thirtieth beat, after which a second period of quickened pulse—*i. e.*, shorter duration of pulse cycle—set in and by the time of the thirty-fourth cycle it had returned to the value observed at the tenth cycle. This corresponds approximately to 29 seconds after the walking started. From this point there was a gradual lengthening of the pulse cycle to the close of the record. The last cycle of the transition period corresponds to a duration of 0.83 second, which was after 59.7 seconds of walking. The pulse-rates taken for the sixth, twelfth, and twenty-fourth minutes of the succeeding interval of walking appear here as a short curve and show, in a general way, the relation of the pulse to the transitional rate as the period progressed. It is seen in the final portion of the figure that the duration of the pulse cycle was nearly uniform for the 10 cycles preceding the close of walking, and was 0.77 second at the moment of transition. The average of the first two pulse cycles of the standing period shows an immediate lengthening to 0.82 second, when again a period of shortening rate followed, which was maintained, more or less irregularly, for 34 beats during the next 27 seconds.

The curve for *Har* (figure 95) is fragmentary, as certain portions of the time record of the photographic film were illegible and the first direct reading of the walking pulse comes approximately 4.5 seconds after the transition. This shows a change in the duration of the pulse cycle from 1.24 second at *X* to 0.84 second as the average of the fifth and sixth cycles. Between the tenth and twentieth cycles the records are missing, but the twentieth shows a slight lengthening, after which a shortening of the pulse cycle took place which reached its maximum at the forty-fourth cycle and was maintained with slight variations to the close of this part of the record. During the rest of the walking period, the pulse cycle lengthened somewhat, and by the time of the final transition was 0.84 second. When the subject stopped walking the cycles immediately began to lengthen and were 0.99 second at the end of the record.

Other members of the squad present similar pictures in the curves given in figures 96 and 97. In the case of *Kim* (figure 96) the duration was 0.79 second with the third and fourth cycles after walking began; a marked lengthening to 0.93 second appeared in the average of the fifth and sixth cycles. This was followed by a series of periods of changing length of the pulse cycles which appear to indicate a rhythm in the pulse. In the transition from walking to standing the first immediate lengthening was followed by a shortening of the cycles, so that the cycle is shorter from the tenth to the fourteenth cycles after walking ceased than during the walking period.

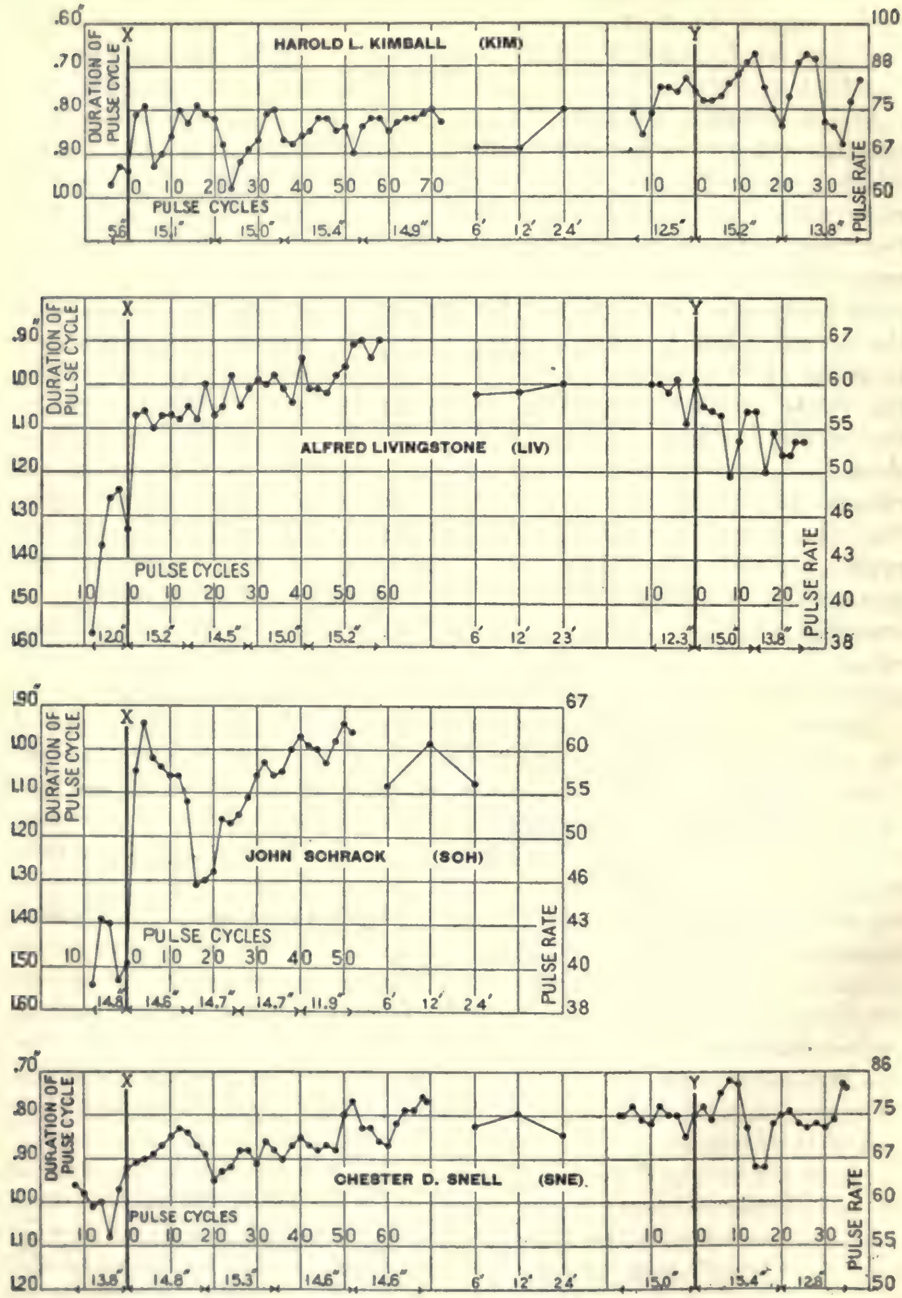

FIG. 96.—Transition pulse curves for Kimball, Livingstone, Schrack, and Snell, Squad B, January 28, 1918.

For detailed explanation, see figure 95.

Liv (figure 96) is the only subject whose pulse cycles do not show a marked lengthening in the duration following the first stimulus of walking. The sixth cycle lengthened slightly to 1.10 seconds, but the curve is in marked contrast to the others and with minor variations is that of a constantly shortening pulse cycle. The immediate lengthening of the cycle at the end of walking continued only through the eighth beat, when it was again followed by a marked shortening period for 6 cycles, after which it continued with an irregularly lengthening interval.

The curve for *Tho* (figure 97) is in the main like the others, but as only 29.7 seconds of the walking transition was secured, it is incomplete. An incipient lengthening of the cycle took place at the sixth beat, but the marked change did not occur until the fourteenth beat, when the duration changed from 0.96 to 1.13 seconds by the twenty-fourth cycle. At that point the quickening of the pulse apparently began, but the record here is incomplete. The pulse cycle was fairly uniform for the 9 cycles at the end of walking, with a duration of 1.18 seconds. This is approximately the duration of the original standing cycle. The cycle reached its maximum length of 1.39 seconds at the tenth beat, after which it shortened to 1.23 seconds at the twentieth beat.

The general picture which these figures for Squad B present is that of a rising curve—*i. e.*, a shortening pulse cycle—beginning from 4 to 8 cycles before the transition to walking and continuing through the transition for a period rarely exceeding 12 cycles, and often not over 4 cycles. The curve then descends, reaching its maximum depression at or near the twentieth cycle, from which a second ascending curve begins.

At the final transition to standing less regularity is seen, but in general it may be said that the response by the heart is prompt, and the curve descends to a minimum at about the tenth cycle, after which there is a more or less pronounced rise, persisting for a few cycles, and then a tendency to fall slightly.

The initial rise while the subject was still standing before walking is accounted for from the routine of the experiment. Previous to the taking of the photographic record the subject had been standing quietly on the treadmill for some time. At a certain moment the assistant gave audible warning to the other assistants that he would start the mill in 15 seconds. This warning could be heard by the subject in the chamber, and a psychically stimulated pulse-rate followed in anticipation of the beginning of walking. The acceleration due to the anticipation of the starting of the treadmill makes it difficult to compare the pulse-cycle durations of the period of standing preliminary to walking with the pulse-cycle durations during walking. Some of the curves indicate that this psychological disturbance is

partially or wholly overcome by the time the walking began, but the majority show that it extended into the walking period. To have given the subject no warning at all would have been equally disturbing for the surprise of the sudden starting of the treadmill would have given the pulse an undue stimulus which would not have been a part of the effort of walking.

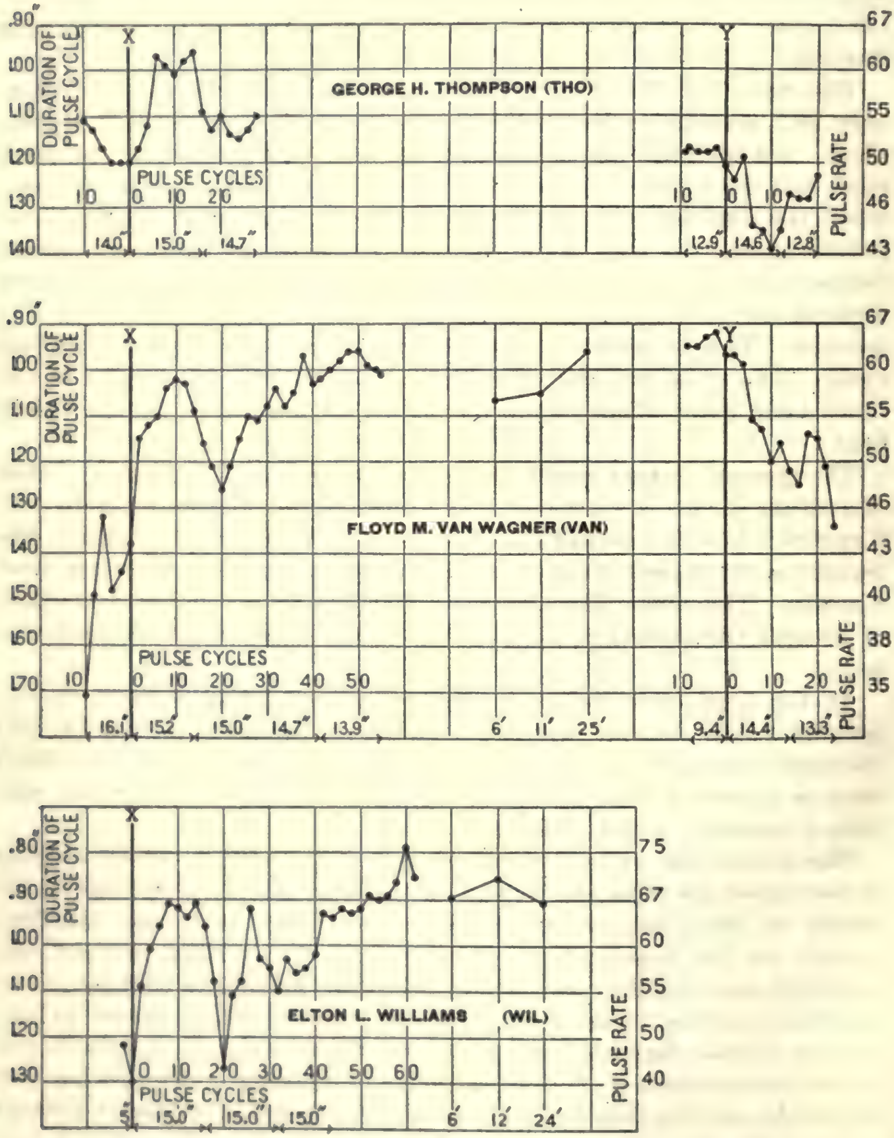

FIG. 97.—Transition pulse curves for Thompson, Van Wagner, and Williams, Squad B, January 28, 1918.

For detailed explanation, see figure 95.

While recognizing the difficulty of selecting a value that would represent the normal pulse-cycle duration for the period of standing preceding walking, due to the psychical disturbance and the shortness of the preliminary standing record, we have nevertheless attempted to make such a selection and find that the pulse-cycle durations while standing were approximately as follows: *Fis*, 1.13; *Ham*, 1.08; *Har*, 1.19; *How*, 0.95; *Kim*, 0.95; *Liv*, 1.36; *Sch*, 1.47; *Sne*, 1.00; *Tho*, 1.15; *Van*, 1.48; and *Wil*, 1.26. Using these figures as a base line, we find that the change to the first peak of the shortened cycles during walking ranged from 0.05 second for *How* to 0.53 second for *Sch*, the average change for the squad being 0.29 second. If these standing pulse cycles are compared with those obtained from the pulse-rates plotted for the sixth and twenty-fourth minutes of walking, it is found that after 6 minutes of walking there has been a change which on an average for the squad would correspond to a shortening in the duration of the pulse cycle equivalent to 0.25 second, while for 24 minutes the change would correspond to 0.30 second.

The average durations of the pulse cycles during the few seconds of walking preceding standing as shown by the curves are as follows: *Fis*, 0.76; *Ham*, 0.84; *Har*, 0.85; *How*, 0.83; *Kim*, 0.78; *Liv*, 1.02; *Sne*, 0.80; *Tho*, 1.18; *Van*, 0.94. At the tenth, twentieth, and thirtieth cycles for standing after walking, the durations of the pulse cycles have lengthened from these figures, on an average for the squad, 0.06, 0.07, and 0.02 second, respectively. When the durations at the same three points are compared with the average standing duration preliminary to walking, we find a shorter duration in the post-walking period, the differences being 0.19, 0.18, and 0.19 second, respectively.

TRANSITION PULSE, SQUAD A.

Figures 98 to 100 give the series obtained with Squad A on February 3, 1918, after a long-continued period of restricted diet. The first curve, that of *Bro* (figure 98), shows the usual change in length of the pulse cycle on the first intimation that the treadmill was to start, which persisted for 8 beats and then gradually lengthened so that at the transition point the pulse cycle was again at its normal length of 0.88 second. As soon as the walking began the duration of the cycle change , and at the fourth beat had shortened to 0.75 second. A slight lengthening followed, so that the duration of the tenth cycle was 0.79 second. The main lengthening, however, took place between the eighteenth an twenty-sixth cycles, when the duration of the pulse cycle changed from 0.74 to 0.88 second. The length of the cycle gradually grew less from this point until the end of this part of the record, but at no time did it become as short as at the first stimulus of walking. In passing from walking to standing, no marked tendency is indicated for a lengthening of the pulse cycle, until after the twentieth cycle,

when the duration changed from 0.79 to 0.86 second at the twenty-sixth beat. After shortening again to 0.81 second at the thirtieth cycle, the duration changed to 0.90 second at the end of the record. The character appears, then, to be the same as in the curves discussed, but with the changes in the cycle lengths slightly delayed. The curve on the whole is more uniform than the others in the group which follow it.

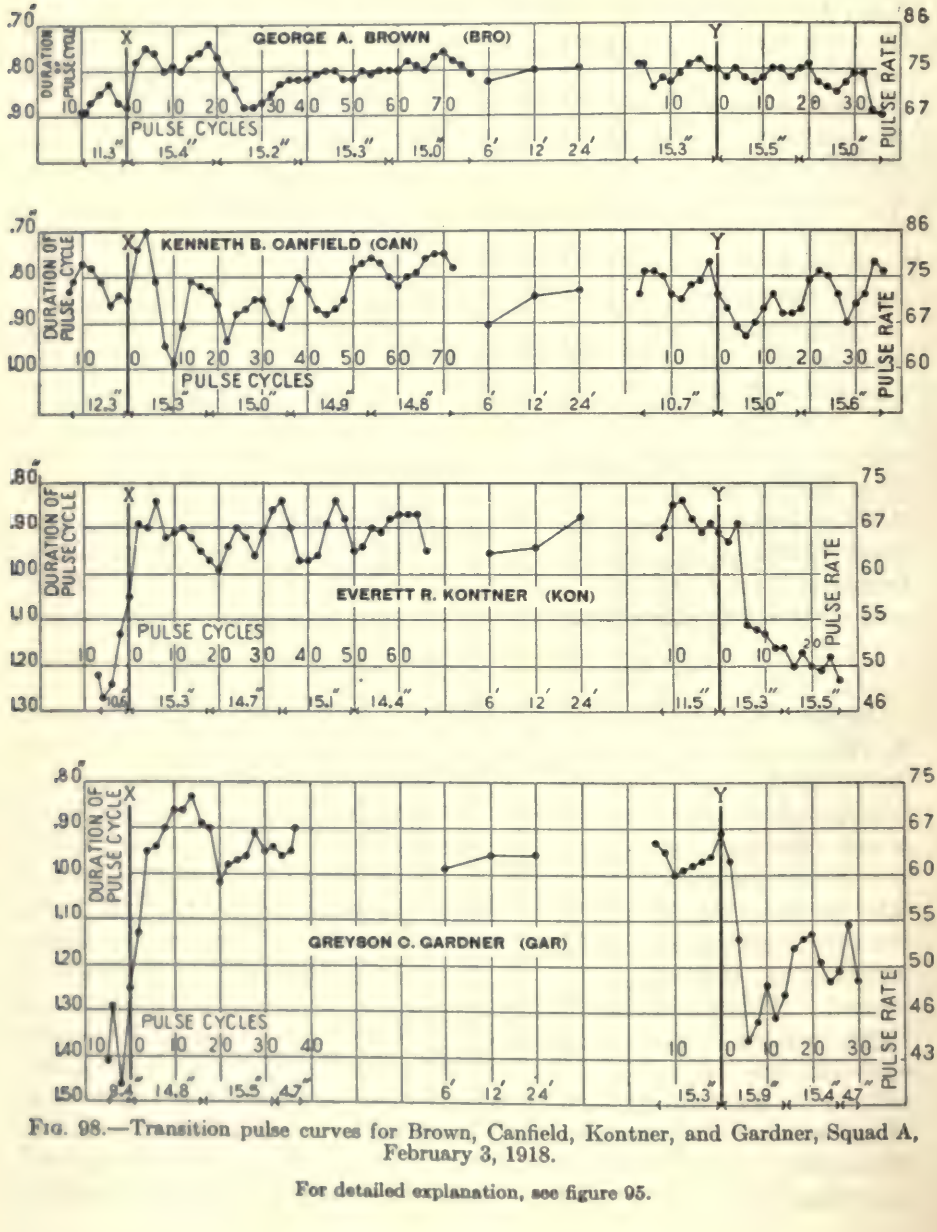

Fig. 98.—Transition pulse curves for Brown, Canfield, Kontner, and Gardner, Squad A, February 3, 1918.

For detailed explanation, see figure 95.

The curve of *Can* (figure 98) shows a fall at the fourth beat following the initial rise as walking began, but the whole curve has more or less a succession of waves, indicating a rhythm in the pulse-cycle duration. An inspection of the intervals of these waves and of *Can's* respiration rate shows no relation between these two factors. This rhythm is likewise apparent in the transition curve of standing following walking. In this curve the changes in the duration of the cycle appear, which have been noted with other subjects, but the lengthening of the pulse is not persistent as with most of the other standing curves, and by the end of the record at 30.6 seconds the duration of the cycles is as short as during the walking period.

The curve of *Kon* for walking (figure 98) shows rather large fluctuations in the length of the pulse cycle. The duration lengthens after the sixth beat, and the following cycles show some indications of periodicity. There is absent here the tendency to a permanent shortening of the duration of the pulse cycle. The final transition shows a sharp change from the walking rate without the tendency to return temporarily to the shorter cycle. By the end of the record, at the twenty-sixth cycle, the duration is 1.23 seconds, or the same as the preliminary standing pulse.

In the curve of *Gar* (figure 98) only 35 seconds of the walking transition are shown, but the lengthening of the pulse cycle after the first reaction to walking is seen between the fourteenth and the twentieth cycles, when the duration changed from 0.83 to 1.02 seconds. Following this there is indicated the usual tendency to a permanent shortened duration of the pulse cycle. *Gar's* curve shows an especially marked change at the initial transition, and the same is seen again at the final transition, where it changed from 0.91 to 1.36 seconds in six cycles. There is here seen also the rebound, reaching 1.13 seconds for the twentieth cycle after the walking ceased.

The curve shown for *Mon* (figure 99) is an exception to the others in that no marked depressions appear, the pulse cycles tending to shorten continuously during the first whole minute of walking. A slight depression in the curve shows a lengthening of the cycle from 0.86 to 0.93 second between the fourth and eighth cycles, which probably corresponds to the more marked depressions at this point seen in other curves. The final transition pulse is also more uniform, but exhibits the usual change at the twentieth cycle from the lengthening duration which immediately appeared with standing.

The pulse of *Pea* (figure 100) was somewhat individual in that the quickened pulse immediately following the change from standing to walking held its level for 10 cycles and the main reaction did not set in until the eighteenth beat. The duration then suddenly changed from 0.87 to 1.19 seconds, which is slower than that of the preliminary standing cycles. The cycle remained at about this duration for the

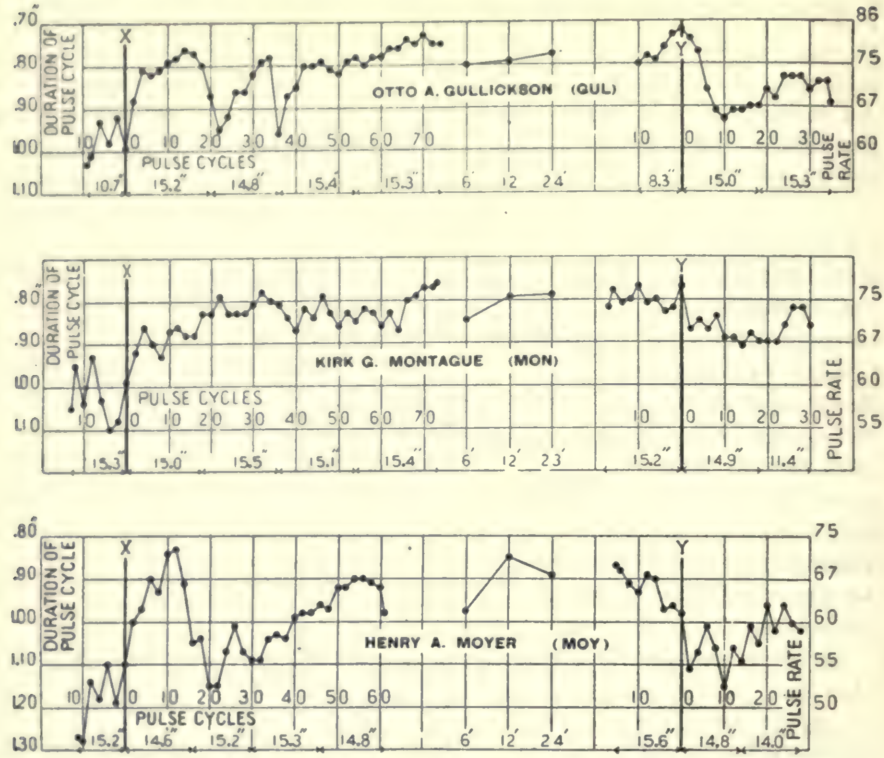

FIG. 99.—Transition pulse curves for Gullickson, Montague, and Moyer, Squad A, February 3, 1918.

For detailed explanation, see figure 95.

next 8 beats, when a fairly uniform shortening occurred. The curve for the standing transition is, in general, not unlike that shown for the majority of the other subjects. The final cycle measured has a duration of 1.19 seconds, which is slightly longer than the standing cycles preliminary to walking.

In the walking transition curve for *Vea* (figure 100), the maximum shortening of the pulse cycle appears to have been reached at the eighth beat, with a duration of 1.00 second, which is maintained through the twelfth cycle. At the thirteenth cycle the photographic tracing shows that *Vea's* heart skipped a beat and in measuring the duration of the double cycle in which the missing thirteenth beat occurred, the average for two beats has been taken although only one beat (the fourteenth) showed on the record. This pulse cycle is marked by an asterisk (*) in the curve. It is seen that the heart tried to make up for this skip by a quickening of the rate in the succeeding two cycles, the duration showing a change from 1.02 to 0.96 second. This is the only instance of a skipped beat noted in all the records. With this exception, the curve of *Vea* is not unlike that of the others in this group.

The average durations of the pulse cycles for standing preliminary to the walking transition, estimated as for Squad B, page 431, are as follows: *Bro*, 0.86; *Can*, 0.82; *Kon*, 1.19; *Gar*, 1.38; *Gul*, 0.96; *Mon*, 1.02; *Moy*, 1.16; *Pea*, 1.05; *Tom*, 0.76; *Vea*, 1.16. The differences between these standing pulse-cycle durations and those for the minimum duration, which immediately follows the change to walking, range from 0.11 second for *Bro* to 0.55 second for *Gar*, with an average change for the squad of 0.24 second. Comparing these standing pulse-cycle durations with the durations which would correspond to the pulse-rates after the sixth and twenty-fourth minutes of walking, we find that the average change has been to shorten the duration 0.15 second for 6 minutes of walking and 0.20 second for 24 minutes of walking.

The average durations of the pulse cycles for Squad A just before walking ceased are found from the curves to be as follows: *Bro*, 0.81; *Can*, 0.81; *Kon*, 0.88; *Gar*, 0.96; *Gul*, 0.77; *Mon*, 0.81; *Moy*, 0.94; *Pea*, 0.92; *Tom*, 0.65; *Vea*, 0.94. Comparing these figures with the durations at the tenth, twentieth, and thirtieth cycles after walking ceased, as was done with Squad B, we find that the average pulse cycle for

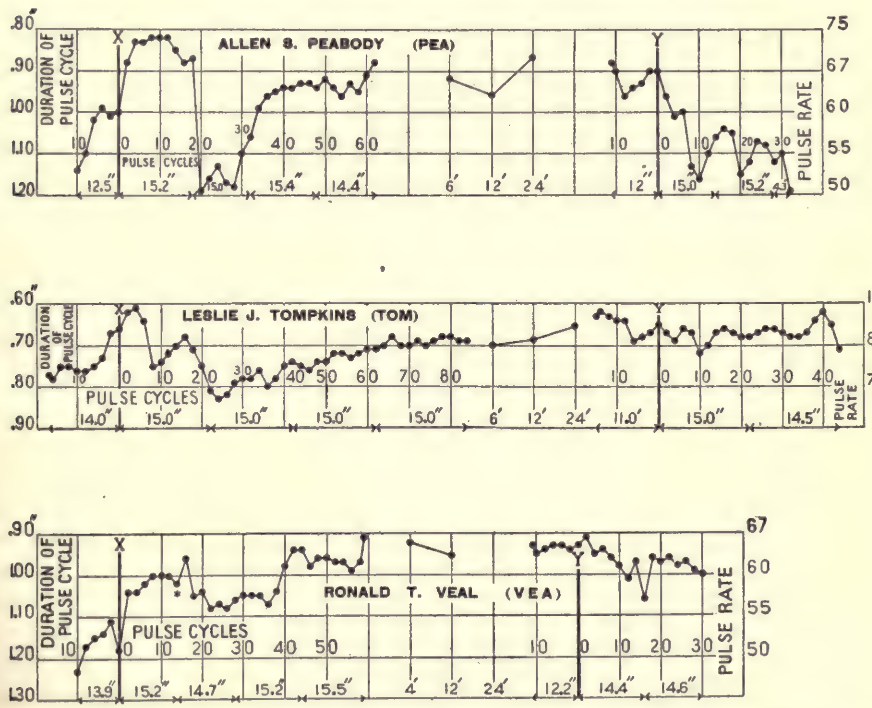

FIG. 100.—Transition pulse curves for Peabody, Tompkins, and Veal, Squad A, February 3, 1918.

For detailed explanation, see figure 95.

the squad has lengthened in its duration over that of walking 0.15, 0.10, and 0.09 second, respectively, while at these same points the pulse cycle is shorter than the average duration for the preliminary standing period by 0.05, 0.08, and 0.08 second, respectively.

TRANSITION PULSE OF A GROUP OF NORMAL MEN.

As was stated at the beginning of this discussion, no transition pulse records were taken while the subjects were living on a normal diet, so that to secure data for purposes of comparison, 5 members of the staff of the Laboratory volunteered to go through the same walking routine in the post-absorptive condition, although no blood-pressure measurements were made at the end of walking. The transition pulse cycles of these men are given in figure 101.

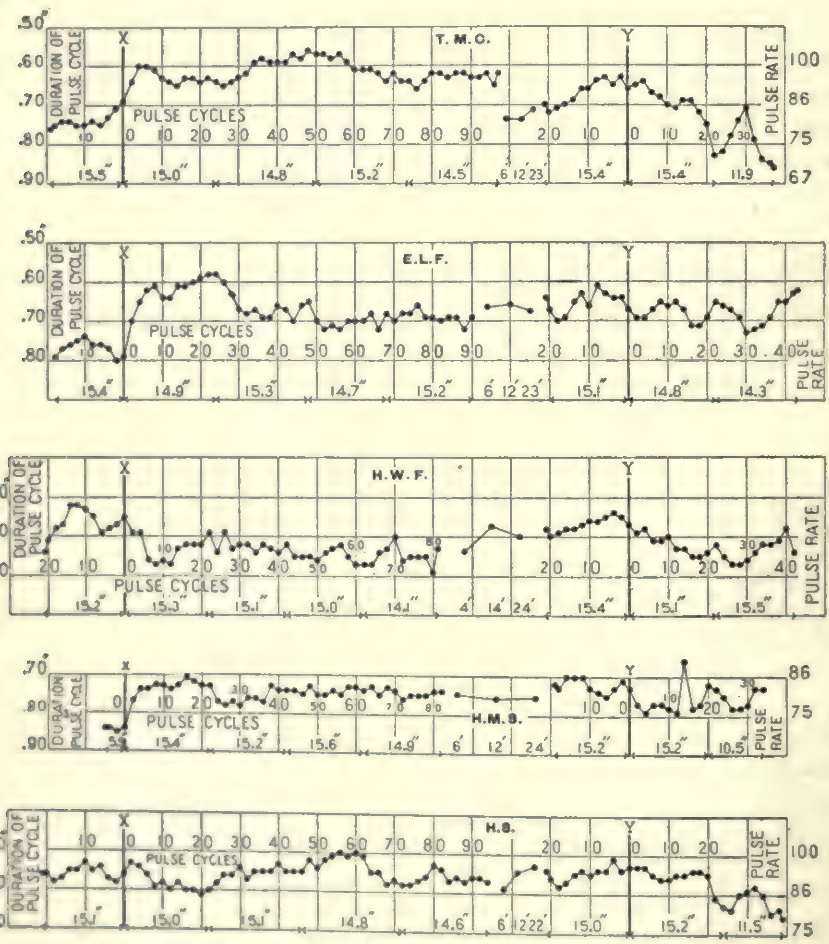

Fig. 101.—Transition pulse curves for a group of five normal men. For detailed explanation, see figure 95.

The pulse cycles of *T. M. C.* show a shortened duration for the first six beats during walking, after which the duration lengthens until the fourteenth cycle. The remaining portion of the curve exhibits no rapid changes, though a gradual shortening of the duration takes place after the twenty-sixth cycle, which is followed by another gradual lengthening after the fifty-sixth cycle. At the transition from walking to standing the pulse cycles had nearly the same duration as at the end of the first transition period, but by the twelfth beat had lengthened to 0.71 second and by the twenty-second beat to 0.83 second. A period of reaction then followed for the next eight beats.

The curve of *E. L. F.* shows the rapid shortening of the cycle to 0.61 second at the eighth beat during walking, followed by four slightly lengthened cycles, and a rise to 0.58 second for the twenty-fourth cycle. From this point there is a rapid fall in the curve to 0.69 second for the thirty-sixth cycle, which value it maintained with fair uniformity during the remainder of this transition period. At the transition from walking to standing, there appears the usual immediate lengthening of the cycle followed by a period of eight beats, during which the cycle again shortens. At the thirtieth beat, the cycle had reached its longest duration of 0.73 second. From this point until the end of the record the cycle continued to shorten so that at the close the duration was 0.62 second, which was shorter than the average during the walking period.

The curve of *H. W. F.* is unlike the other curves of this group or of Squads A and B in that the pulse cycle undergoes no shortening in the transition from standing to walking. It is true that during the preliminary 15.2 seconds of standing, the duration had shortened from the twentieth to the fourteenth cycles preceding the transition, which was coincident with the warning that the walking was about to begin; this effect had, however, passed away and a secondary shortening was stopped and changed to a lengthened cycle when the walking began. Although the records have been searched, no explanation for this unusual behavior is apparent. In the case of *H. M. S.* no signal was given and the starting of the treadmill was entirely unexpected by the subject. The transition cycle therefore shows no influence of a preliminary warning. The change in the duration of the pulse cycle during walking was from 0.84 to 0.76 second in the first two cycles, and reached 0.71 second by the sixteenth cycle. The duration lengthened from this point to 0.78 second at the twenty-sixth cycle. For the last half of this transition record, the cycle lengths are unusually uniform, being not far from 0.74 second. The curve for the transition from walking to standing differs in no marked respect from the other curves except that the thirteenth and fourteenth cycles indicate a sudden shortening to an average of 0.66 second, with an immediate return to the previous duration.

The curve of *H. S.* does not show large changes, but there is apparent the usual shortening of the pulse cycles following the stimulus of walking. By the eighth cycle, the duration is again as long as during the standing period, and reaches its maximum duration at the twentieth cycle; subsequently it shortens slowly to 0.60 second at the sixtieth cycle. At the transition from walking to standing, there does not appear to be a response until the twentieth cycle, when the duration increases suddenly from 0.65 to 0.73 second. By the end of the record, the cycle is slower than during the preliminary standing period, and in this respect it is similar to that of *T. M. C.*

The average pulse-cycle duration during standing preliminary to the walking transition as estimated from the curves is as follows: *T.M.C.*, 0.75; *E.L.F.*, 0.78; *H.W.F.*, 0.68; *H.M.S.*, 0.84; *H.S.*, 0.66 second. The values of *H.W.F.* and *H.S.* are exceptional, for the corresponding pulse-rates appear to be higher by the equivalent of 13 and 11 beats per minute, respectively, than the rates counted during the 10-minute standing period and given in table 101. (See page 449.) There is, however, no known reason for the variations with these subjects which would not have applied equally to the other men, both in the normal group and in Squads A and B. If we accept these figures for pulse-cycle durations, the changes between the values for the preliminary standing period and the durations that occur at the apex of the wave immediately following the beginning of walking range from −0.09 second for *H.W.F.* to 0.17 second for *E.L.F.*, with an average of 0.07 second for the group. If a comparison is also made between these preliminary standing values and the durations as found from the pulse-rates after 6 and 24 minutes of walking, the average pulse-cycle duration appears to be 0.03 second shorter than the average standing value after 6 minutes of walking and 0.05 second after 24 minutes. These figures include the values of *H.W.F.* and *H.S.*; excluding these two, the change in the duration appears to be 0.08 second shorter after both 6 and 24 minutes of walking than when standing.

From the standing transition curves it is found that the average pulse-cycle duration for walking immediately preceding standing is as follows: *T.M.C.*, 0.68; *E.L.F.*, 0.65; *H.W.F.*, 0.67; *H.M.S.*,0.72; *H.S.*, 0.65 second. At the tenth, twentieth, and thirtieth cycles after walking ceased, we find that the durations for the group have lengthened 0.03, 0.04, and 0.06 second, respectively. Using the preliminary standing values as a basis of comparison, we find that the post-walking values are, for the group, 0.04 second shorter at the tenth cycle than the prewalking values, exactly the same at the twentieth cycle, and 0.01 second longer at the thirtieth cycle. If we compare these sets of figures with those found in a similar way for Squads A and B and given on pages 431 and 435, it appears that this lengthening in the pulse-

cycle duration immediately after walking was greater for the two diet squads than for the five normal men.

The most apparent difference between these five curves and those for Squads A and B, given in figures 95 to 100, inclusive, is that they are flatter and do not show such wide fluctuations. It should be remembered in this connection, however, that the pulse-rates of these normal subjects were faster than those of Squads A and B; consequently, in the 60 seconds of the walking record, there are more cycles to plot and the individual differences will not be so large. *Bro* (figure 98) and *Tom* (figure 100) had pulse-rates more nearly like those of the normals, and the curves for these men show more similarity to those of the normal subjects. Moreover, a change of the same increment with a pulse of a slow rate has a greater percentage value than with a pulse of faster rate. Before it can be definitely stated that one group shows greater fluctuations than another, these variations should be compared on some form of percentage basis. An attempt to do this is made in table 97, in which the average minimum and maximum pulse-cycle lengths in the walking and standing portions of the transition records have been noted, and the percentage increase of the maximum over the minimum duration is given. This takes into account the two extremes but does not allow for the possibility of more frequent variations occurring with one group than with another. The figures in the table show that in the walking transition the average difference between these two extremes is least with the five normals and greatest with Squad A on a 120-day restricted diet. In the standing transition following walking, Squad B has the smallest percentage difference, and the five normals have the largest difference.

TABLE 97.—*Comparison of the minimum and maximum durations of the pulse cycles while walking and standing for a group of normal men, Squad B, and Squad A.*

Groups of subjects and conditions compared.	Minimum and maximum duration of the pulse cycle during—							
	60 seconds of walking following standing.				30 seconds of standing following walking.			
	Min.	Max.	Increase above minimum.		Min.	Max.	Increase above minimum.	
	sec.	*sec.*	*sec.*	*p. ct.*	*sec.*	*sec.*	*sec.*	*p. ct.*
5 normals	0.62	0.73	0.11	17.7	0.65	0.78	0.13	20.0
Squad B, 20-day diet	0.89	1.10	0.21	23.6	0.88	1.01	0.13	14.8
Squad A, 120-day diet	0.78	1.00	0.22	28.2	0.87	1.03	0.16	18.4

It would appear, then, that during the walking transition Squads A and B had not only larger pulse-cycle variations than the normals had, but when calculated as in table 97, the percentage changes were also larger. For the transition from walking to standing, the actual

differences in the extremes are practically alike for the three groups, but no striking relationship is apparent on the percentage basis.

A comparison of the changes between the average standing pulse-cycle duration preliminary to walking and that of the average duration of the first crest after walking began shows for the 5 normals a change of 0.07 second, for Squad B 0.29 second, and for Squad A 0.24 second, or a percentage change from the standing pulse-cycle duration of 10 per cent for the 5 normals and 25 and 23 per cent for Squads B and A, respectively.

A comparison between the changes in the duration of the pulse cycle for standing and the durations that would correspond to the pulse-rate found after 6 and 24 minutes of walking shows the normals had the least tendency to a shorter duration.

The curves of all three groups show that the pulse cycle lengthened after the first reaction to the stimulus of walking. This change to a lengthening cycle occurred between the fifth and tenth cycles, as a rule, both with the normals and with Squads A and B. The lengthening of the cycles continued to about the twentieth beat, when again a shortened duration appeared which usually was persistent, and the cycle did not again return to the duration shown at approximately the twentieth beat.

Recognizing the facts that the data here available are incomplete and that we are dealing with an organ extremely sensitive to the mental and physical conditions of the subject, which thus makes conclusions upon its normal behavior difficult, we may say that there appears to be no decrease in the promptness with which the heart responds to the stimulus of walking, and the other characteristics of the pulse aside from rate have not been fundamentally changed by the restricted diet. From the foregoing it is seen that (1) the average percentage variation for Squad A is greater than that for Squad B; (2) that of the three groups the 5 men with normal diet showed the smallest variation in the pulse-cycle duration in the changes from standing to walking and from walking to standing, and likewise the least variations in the maximum and minimum durations during the first 60 seconds of walking; (3) that these men showed less change than the men with low diet between the preliminary standing pulse-cycle duration and the duration which would correspond to the rates found after walking 6 and 24 minutes. These facts would seem to indicate a greater sensitivity of the heart to demands upon the circulatory system when the body was existing on a restricted diet.

INFLUENCE UPON PULSE-RATE OF WALKING ON A TREADMILL.

In connection with the walking experiments of January 6 and 28 and February 3, it was planned to secure the pulse records photographically with the subject sitting and standing preliminary to walking, at the first, sixth, twelfth, and twenty-fourth minutes of

walking; and finally a few wrist counts during the 10 minutes following walking. The difficulties in this program lay in the overlapping of the experiments, due to unavoidable delays at one point or another in the routine, to an occasional poor contact of the body electrodes, or to a defective grounding of the subject. These difficulties made it impossible to get a complete record in every instance; those obtained are given in tables 98, 99, and 100. The pulse-rates at the sixth, twelfth, and twenty-fourth minutes of walking are also shown for January 28 and February 3 in figures 95 to 100.

If an attempt is made to use only averages which include a complete series for each man, we find that there are too few for a satisfactory comparison; the average pulse-rates per minute for each squad are therefore for such records as are available in each series of observations. The comparisons are made from these averages, which in some cases consist of the entire squad of 12 subjects, while in others a smaller number are included.

Table 98 gives the records of January 6 with Squad B, normal. If the sitting pulse records are compared with those taken the evening previous in connection with the series of psychological tests (see p. 403), we find in the main an agreement that is as close as could be expected with conditions so different. But the pulse-rates of *Sch* and *Sne* (92 and 97) are so high and so much higher than the other sitting records that it indicates the presence of an unusual stimulus. This is the more apparent when the standing pulse is considered, for whereas all the other subjects show an increase, these two men show a drop of 24 and 28 beats, respectively. The average sitting pulse for the group is therefore taken as 72 beats and does not include these two high pulse-rates of *Sch* and *Sne*.

The records of the standing pulse were taken after the subjects had been standing 10 minutes. In a few cases on this date the subjects stood on the treadmill, while others stood in an adjoining room. The average standing pulse includes both locations, and for the 11 subjects is 79 beats, which is an increase over the average sitting pulse for 8 subjects of 10.0 per cent.

An inspection of this table shows that in most cases by the end of one minute of walking, the pulse-rate increased over that for standing, but that the rate for *Fis*, *Ham*, and *Liv* was slightly lower. The average for the 12 men is 88. This is an increase of 22 per cent over the average sitting pulse-rate and of 11 per cent over the average standing rate. By the end of 6 minutes of walking the pulse-rate shows in 8 cases a decrease from the rate after one minute of walking, ranging from a maximum of 8 beats for *Har* and *Wil* to 2 beats for *Sne* and *Tho;* of the remaining 4 subjects, *Liv's* pulse increased 3 beats and *Kim's* and *Ham's* 1 beat each; *McM's* pulse showed no change; the average is 85 beats or an increase of 8 per cent over the standing

TABLE 98.—*Pulse-rate preceding, during, and following walking in the treadmill chamber and percentage change from the standing rate—Squad B, normal, January 6, 1918.*

Subject.	Rate per minute.		Rate at minutes after walking began.				Sitting outside chamber. Rate at minutes after walking ceased.	
	Sitting outside chamber.	Standing outside chamber.	1′	6′	12′	24′	2′	7′
Fis:								
Rate	73	82	81	78	79	86	62	68
P. ct. change	....	....	− 1	− 5	− 4	− 5	....	....
Har:								
Rate	68	79	96	88	88	92	62	64
P. ct. change	....	....	22	11	11	16	....	....
How:								
Rate	....	77	96	91	96	101	84	82
P. ct. change	....	....	25	18	25	31	....	....
Ham:								
Rate	82	95	94	95	99	104	72	76
P. ct. change	....	....	− 1	0	4	9	....	....
Kim:								
Rate	70	80	86	87	83	90	72	74
P. ct. change	....	....	8	9	4	13	....	....
McM:								
Rate	76	84	100	100	89	90	72	76
P. ct. change	....	....	19	19	6	7	....	....
Sch:								
Rate	92	68	83	80	85	78	60	54
P. ct. change	....	....	22	18	25	15	....	....
Liv:								
Rate	69	71	70	73	79	76	62	60
P. ct. change	....	....	− 1	3	11	7	....	....
Sne:								
Rate	97	69	90	88	86	91	70	76
P. ct. change	....	....	30	28	25	32	....	....
Tho:								
Rate	56	77	77	75	78	82	52	56
P. ct. change	....	....	0	− 3	1	6	....	....
Van:								
Rate	....	....	83	80	81	84	54	56
P. ct. change	....	....	....	....	....	....	....	....
Wil;								
Rate	78	83	96	88	83	93	64	62
P. ct. change	....	....	16	6	0	12	....	....
Average	[1]72	79	88	85	85	89	66	67
P. ct. change	....	....	11	8	8	13	....	....

[1]Omitting *Sch* and *Sne*.

pulse. At the twelfth minute the average pulse-rate was like that of the sixth minute and by the end of 24 minutes it was but 1 beat per minute higher than at the end of the first minute of walking.

The sitting pulse following walking, which was taken at the wrist, had an average of 66 beats by the second minute; this was below the sitting pulse taken photographically before walking. It was still below the initial pulse after 7 minutes of sitting, although there was a slight rise to 67 beats. If these pulse-rates were plotted with the rate as ordinates and the time as abscissæ, the resultant curves would show a fall between the end of the first and of the sixth minutes, followed by

a return at the end of 24 minutes to a rate not differing greatly from that at the end of the first minute. The exact location of the lowest point of the depression which occurs between the first and sixth minutes is not evident from the data in the table as no records were taken on this day between these two points. Some indication of this may be seen from figures 95, 96, and 97, in which a curve has been inserted between the curves of the two transitional pulse records, which shows the relation of the pulse-rates at the sixth, twelfth, and twenty-fourth minutes. It is seen that in the majority of cases the pulse-rate is lower at the sixth minute than it was at the end of the transitional period.

The pulse-rates for Squad B on January 28 are given in table 99. On this date an attempt was made to enlarge the pulse data by securing more than one record or observation for the sitting and standing pulse and to obtain records both with the subject standing in an adjoining room as well as standing on the treadmill. The sitting pulse recorded at the start is the average of 2 observations for *How*, *Ham*, and *Van;* 3 for *Fis*, *Sne*, and *Tho;* 4 for *Kim;* and 5 for *Liv*. For the period of standing outside the chamber there was 1 observation each for *Har*, *Lon*, and *Sch;* 2 for *Tho;* 3 for *Fis*, *How*, *Ham*, *Sne*, and *Van;* and 4 for *Kim*. In the observations taken with the subject standing on the treadmill *Ham*, *Sch*, *Liv*, and *Wil* each have 1, *Sne* 2, *Van* 3, *Fis* 4, and *Kim* 5.

As described in the section on technique (see p. 130), the pulse records were also increased on this date over those of January 6 by making, with the aid of a stop-watch, a visual count of 20 deflections of the shadow of the string of the galvanometer across the face of the camera at the end of each minute of walking. Since the pulse was photographed for the transition from standing to walking, which continued through the first minute, no photograph was taken for the record after 1 minute of walking, as was done on January 6, but instead a visual count was made.

The figures given for the sixth, twelfth, and twenty-fourth minutes were counted from the photographs, while the other pulse-rates were counted visually from the deflections of the galvanometer string. Failures to secure records for *Lon* and *Tho* for the walking periods were due to illegible records on account of defective grounding of the subjects. Other missing records are due to various causes. It has been necessary, therefore, to take for the averages such data as were available.

All of the subjects had a low pulse-rate, regardless of whether they were sitting, standing, or walking. The average for the sitting pulse for the 7 subjects whose records are available is 46 beats, the figures for the individual subjects all being lower than those for the sitting pulse taken the evening previous and given in table 87. After sitting for 10 minutes the subjects stood and the records were taken as a rule

TABLE 99.—*Pulse-rate per minute preceding, during, and following walking in the treadmill chamber with percentage change from rate standing in chamber before walking—Squad B, January 28, 1918.*

Subject.	Rate per minute.			Rate at minutes after walking began.																									Standing in chamber, cover open; rate at seconds after walking ceased.				Sitting outside chamber, rate after walking ceased.		
	Sitting outside chamber.	Standing outside chamber.	Standing in chamber, cover open.	1′	2′	3′	4′	5′	6′	7′	8′	9′	10′	11′	12′	13′	14′	15′	16′	17′	18′	19′	20′	21′	22′	23′	24′	25′	30″	60″	90″	120″	4′	8′	9′
Fis:																																			
Rate	47	58	52	71	68	63	61	63	61	62		65	61		67	66		63	64	69	64		69	72		71	72	71				59	49	46	
P. ct. change				37	31	21	17	21	17	19		25	17		29	27		21	23	33	23		33	38		37	38	37							
Har:																																			
Rate		53		84	81	75	75	79		75			73		79	77	79	79						75	71	71							41	[1]40	39
P. ct. change[2]				58	53	42	42	49		42			38		49	45	49	49						42	34	34									
How:																																			
Rate	43	60		69	67	63	63	65		72	69			66		70	70		75	73	72		74		73	75		78	67	63	67	64	56		56
P. ct. change[2]				15	12	5	5	8		20	15			10		17	17		25	22	20		23		22	25		30							
Ham:																																			
Rate	49	58	52	71	63	62	63	60	66	65	67	66	67	67	69	67		68			70		71			69	73	71	55	54	56	58	45	51	
P. ct. change				37	21	19	21	15	27	25	29	27	29	29	33	29		31			35		37			33	40	37							
Kim:																																			
Rate	51	60	61	69	69	67	67	69	68	67	67	65	69	67	67	69	70	68	70	78	72	76	71	75	72	73	75	73	73	69	73	74	53	57	[3]56
P. ct. change				13	13	10	10	13	11	10	10	7	13	10	10	13	15	11	15	28	18	25	16	23	18	20	23	20							
Sch:																																			
Rate		45	55	66	65	56	59	59	56	62		60		61	61		58						57	54	59		56	57	44	44	44		[4]40		38
P. ct. change				20	18	2	7	7	2	13		9		11	11		5						4	−2	7		2	4							
Liv:																																			
Rate	38	41	45	60	59	56	58	60	59	58	62	61	62	62	59	58		56			57		58	58		60		60	47	46	50	47	43		39
P. ct. change				33	31	24	29	33	31	29	38	36	38	38	31	29		24			27		29	29		33		33							
Sne:																																			
Rate	51	72	62	75	69	74		71	73	70	68		80	75	75				71	79						79	71		68	62	72	72		50	
P. ct. change				21	11	19		15	18	13	10		29	21	21				15	27						27	15								
Van:																																			
Rate	40	48	43	58	56	54	51	56		57	59		57	57				56	59		59	58	63	61				63	47	51	43	46	39		40
P. ct. change				35	30	26	19	30		33	37		33	33				30	37		37	35	47	42				47							
Wil:																																			
Rate			46	65	65	65	66	61	67	69	65		69		71						70			67	69	71	66		60	58	58	68		[1]46	
P. ct. change				41	41	41	43	33	46	50	41		50		54						52			46	50	54	43								
Average	46	55	52	69	66	64	63	64	64						69												69		60	58	60	61	46	49	45
Per cent				33					23						33												33								

[1]Rate at 7 minutes. [2]Based on rate standing outside chamber. [3]Rate at 10 minutes. [4]Rate at 5 minutes.

after 1 minute and 10 minutes of standing, with as many intermediate records as opportunity permitted. In each instance there was an increase in pulse ranging from 3 beats or 8 per cent for *Liv* to 21 beats or 41 per cent for *Sne*, with an average pulse-rate of 55 for the 9 subjects, an increase of 9 beats or 20 per cent. The average pulse-rate with the subject standing in the chamber is slightly lower than the pulse taken outside the chamber, but the changes are both positive and negative. These pulse-rates were counted at different intervals of standing and there is not the uniformity in this respect that there was with the other pulse-rates taken for standing. The records as a whole may be said to show that the subjects had adapted themselves to the conditions and that there was nothing abnormal about any of the pulse-rates. The records for those counted at the end of 1 minute of walking all show an increase above the standing pulse inside the chamber, varying from 8 beats or 13 per cent for *Kim* to 19 beats or 41 per cent for *Wil*. The average pulse-rate for the group had increased 17 beats to a rate of 69 or an increase of 33 per cent. The same fall in pulse-rate between the end of 1 minute and the end of 6 minutes is noted here as was observed on January 6, *Wil* being the only exception to this general behavior.

The fact that there was a drop in the pulse from the first minute is evident in a study of the rates shown for the intervening minutes. It is seen that the heart had begun to recover from its first stimulus of walking at the end of 2 minutes, for there was a drop in every instance, except for *Kim*, whose rate remained the same but fell off by the end of 3 minutes of walking, and for *Wil*, whose pulse first showed a drop at the fifth minute. Eight of the 10 sets available for comparison show that the fall following 1 minute of walking reached its lowest point by the end of the third or fourth minute. By the end of 6 minutes, in 5 out of 7 cases the rate had increased from this low point, though it had not reached the rate of the first minute. By the end of 12 minutes *Wil* had a pulse faster than at the end of 1 minute, while the others were about at the 1-minute rate or slightly below. Unfortunately, there are only 6 records reported for the twenty-fourth minute, but if the count for either the twenty-third or twenty-fifth minute is used in place of that lacking for the twenty-fourth minute, it is seen that *Har*, *Sch*, and *Sne* still had lower pulse-rates than after 1 minute of walking, while *Liv* had the same. The other subjects had pulse-rates slightly in excess of that following 1 minute of walking. This relationship was likewise found on January 6 (table 98), *viz.*, that 1 minute of walking was sufficient to bring the pulse to a rate that 24 minutes of walking did not materially change.

During the 2 minutes which immediately followed walking, the subjects were standing on the treadmill while the blood pressures were being measured. It is obviously impossible to compare the pulse-rates

under these conditions. It may be said, however, that for the 7 cases where the rates are given at both 30 and 120 seconds, the average at 30 seconds is 9 beats below the average for the same seven subjects at their last walking rate, and that the rate at 30 seconds is already at a level which is unchanged by standing 120 seconds. Two minutes of sitting, which was a total of 4 minutes after the walking ceased, was sufficient to bring the pulse down to the original sitting rate.

The pulse records for Squad A in the walking test of February 3 appear in table 100. The details of this test were carried out in the same manner as those for the experiment on January 28. The sitting and standing pulses were the averages of 2 to 5 counts, except for *Moy* and *Pea* while sitting, and *Gar*, *Moy*, and *Pea* while standing in the chamber, when only 1 count was made. The sitting pulse of *Tom* was relatively high as compared with that for other members of the squad, but this is in keeping with his sitting pulse for the evening previous as shown in table 86.

The average sitting pulse for the 11 members of the squad was 52. With the subject standing outside the chamber, the pulse-rate was greater in every instance except for *Gar*, with whom there was a drop of 2 beats. The sitting pulse in his case is the average of counts taken after 2, 3, 8, and 9 minutes and the standing pulse was counted after 1, 3, and 5 minutes of standing. This seems a very definite case of not only an absence of increased rate for standing over that for sitting but an actual, though small, drop in the pulse-rate. In the 8 observations available for comparison the average pulse-rate rose 11 beats with standing to a rate of 63 or 21 per cent above the sitting rate. The rate with the subject standing on the treadmill varies somewhat from the rate when he was standing outside the chamber, as was the case with Squad B on January 28. In 4 cases there was an increase, but the average fell to 60, a change similar to that observed for Squad B on January 28.

After 1 minute of walking, we find that, except for *Can*, the pulse-rates all increased as compared to the rate while standing outside the chamber. This would seem to indicate that *Can's* high pulse-rate of 81, although an average of three counts, was due to some unusual stimulus. The average pulse-rate for all of the subjects at the end of one minute of walking was 72. This was an increase of 20 beats or 38 per cent above the sitting rate, and 12 beats or 20 per cent above the standing rate inside the chamber. As was found with Squad B on January 28, the pulse-rate fell after the initial rise due to the stimulus of walking, and at the end of the second minute had dropped by an average of 4 beats, and 5 beats by the end of the fourth minute. The sixth minute showed a recovery of 2 beats. Subsequently, the rate varied slightly, reaching at the close of 12 minutes an average of 72 for 9 subjects, and 73 at the end of 24 minutes for 8 subjects. This

TABLE 100.—*Pulse-rate per minute preceding, during, and following walking in the treadmill chamber with percentage change from rate standing in chamber before walking—Squad A, February 3, 1918.*

Subject.	Rate per minute. Sitting outside chamber.	Standing outside chamber.	Standing in chamber, cover open.	Rate at minutes after walking began. 1′	2′	3′	4′	5′	6′	7′	8′	9′	10′	11′	12′	14′	15′	16′	17′	18′	19′	20′	22′	23′	24′	Standing in chamber, cover open; rate at seconds after walking ceased. 30″	60″	90″	120″	Sitting outside chamber, rate after walking ceased. 4′	8′	9′
Bro:																																
Rate	60	64	68	76	74	73	74	75	73	...	79	78	76	...	75	74	...	77	...	73	...	73	74	74	75	70	70	69	70	55	...	57
P. ct. change	...	...	...	12	9	7	9	10	7	...	16	15	12	...	10	9	...	13	...	7	...	7	9	9	10	3	3	1	3	...	...	...
Can:																																
Rate	62	81	67	74	67	65	69	69	66	69	68	...	72	...	71	69	...	68	...	70	...	75	...	...	73	75	70	78	82	48	...	63
P. ct. change	...	...	...	10	0	−3	3	3	−1	3	1	...	7	...	6	3	...	1	...	4	...	12	...	...	9	12	4	16	22	...	...	...
Kon:																																
Rate	41	49	...	63	61	63	57	58	63	...	...	...	60	61	64	64	61	...	73	...	...	63	63	65	69	46	44	46	48	[1]44	48	...
P. ct. change[2]	...	...	...	29	25	29	16	18	29	...	...	...	22	25	31	31	25	...	49	...	...	29	29	33	41	−6	−10	−6	−2	...	...	...
Gar:																																
Rate	45	43	44	70	65	64	57	60	61	...	61	59	63	61	...	...	...	63	63	...	62	64	64	64	63	46	46	47	54	42	39	...
P. ct. change	...	...	...	59	48	45	30	36	39	...	39	34	43	39	...	...	...	43	43	...	41	45	45	45	43	5	5	7	23	...	...	...
Gul:																																
Rate	57	71	67	80	75	76	75	...	76	...	76	...	...	...	76	76	...	76	...	79	...	78	77	...	78	56	63	60	65	57	...	52
P. ct. change	...	...	...	19	12	13	12	...	13	...	13	...	...	...	13	13	...	13	...	18	...	16	15	...	16	−16	−6	−10	−3	...	...	...
Mon:																																
Rate	49	56	61	73	71	70	72	72	71	...	73	...	72	...	76	75	...	74	74	78	79	82	79	76	...	63	64	63	60	55	56	...
P. ct. change	...	...	...	20	16	15	18	18	16	...	20	...	18	...	25	23	...	21	21	28	30	34	30	25	...	3	5	3	−2	...	...	...
Moy:																																
Rate	45	...	48	59	63	62	60	66	62	64	63	...	64	...	71	63	64	62	...	67	63	65	65	68	67	57	51	51	54	43	...	49
P. ct. change	...	...	...	23	31	29	25	38	29	33	31	...	33	...	48	31	33	29	...	40	31	35	35	42	40	19	6	6	13	...	...	...
Pea:																																
Rate	47	...	63	65	64	61	63	61	65	63	62	63	63	63	63	64	62	62	64	65	63	62	62	64	69	54	50	49	52	[1]47	46	...
P. ct. change	...	...	...	3	2	−3	0	−3	3	0	−2	0	0	0	0	2	−2	−2	2	3	0	−2	−2	−2	10	−14	−21	−22	−17	...	...	...
Pec:																																
Rate	42	52	55	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	[1]47	52	...
Tom:																																
Rate	72	84	76	87	85	80	78	82	86	...	85	...	87	...	87	85	...	85	...	88	...	90	90	...	92	85	81	85	90	[1]62	66	...
P. ct. change	...	...	...	14	12	5	3	8	13	...	12	...	14	...	14	12	...	12	...	16	...	18	18	...	21	12	7	12	18	...	...	...
Vea:																																
Rate	49	...	49	...	59	...	65	...	...	...	60	...	64	...	63	61	...	64	...	...	...	...	...	...	...	60	54	55	57	[1]47	...	41
P. ct. change	...	...	...	...	20	...	33	...	...	...	22	...	31	...	29	25	...	31	...	...	...	...	...	...	...	22	10	12	16	...	...	...
Average	52	63	60	72	68	68	67	68	69	...	...	...	...	...	72	...	...	...	...	...	...	...	...	...	73	61	59	60	63	50	52	
Per cent	...	...	...	20	...	...	...	...	15	...	...	...	...	...	20	...	...	...	...	...	...	...	...	...	22	...	...	...	...	...	...	...

[1]Rate at 5 minutes. [2]Based on rate standing outside chamber.

was but 1 beat higher than for 9 subjects at the end of 1 minute, and it is in harmony with the results found with Squad B on January 6 and January 28. During the first 30 seconds of standing following walking, the average pulse-rate fell 12 beats from the rate at 24 minutes, and varied but 1 or 2 beats during the 120 seconds of standing, thus indicating the quick response of the heart to the requirements of the body. This rate was practically the same as that found during the preliminary standing period. In this respect, Squad A differed from Squad B on January 28 when the pulse did not return to the preliminary standing rate, at least in the time cóvered by the observation. The pulse-rates counted after 2 minutes of sitting, *i. e.*, 4 minutes after walking ceased, show a further fall in rate of 13 beats. Taking for an average the rates at the fourth and fifth minutes, we find it to be 50 beats, or 4 per cent below the sitting pulse at the start of the experiment. By the end of 8 or 9 minutes of sitting, the pulse-rate had recovered and the average of 11 men was 52, or the same as the original sitting pulse.

In table 101 are given the pulse-rates of 5 normal subjects referred to on page 436. The pulse-rates for the sitting position, preliminary to walking, are the average counts taken each minute for the 10 minutes during which the subject sat, except for *E.L.F.* and *H.S.*, whose averages are from counts made for 6 and 7 minutes, respectively, of the 10 minutes of sitting. During the standing period, the average in each case is from counts taken each minute for 11 minutes. It is seen that the rate for *H.M.S.* remains very nearly uniform for the entire walking period at about 9 beats above the standing rate. While the data for *H.W.F.* are not so complete as for the others, they show a smaller initial change in the rate with greater variations during the period of walking. *E.L.F.* has a larger initial change than the others and this rate is maintained throughout the walking period on the whole rather uniformly. The rate of *T.M.C.* after the first minute shows a decided drop which is then maintained approximately 5 beats above the standing rate. The changes in the rate of *H.S.* are similar to those of *T.M.C.* for the first third of the period but show greater variations as the period progresses. The average increase in the pulse-rate from sitting to standing is 8 beats or 12 per cent of the sitting rate, and the increase due to walking 1 minute is 9 beats with a rate of 85 beats, or 12 per cent of the standing rate. During the succeeding 3 minutes, there was a fall to an average rate of 81 beats at the fourth minute and a subsequent increase to 85 beats by the sixth minute. The latter was the rate found at the end of the first minute and was maintained practically unchanged during the remainder of the walking period. The fall in the pulse-rate following the first minute of walking, and its subsequent recovery by the sixth minute is in character the same as with the two diet squads, though perhaps not so pronounced. There are

TABLE 101.—*Pulse-rate per minute preceding, during, and following walking in the treadmill chamber with percentage change from standing rate; 5 normal men.*

Subject.	Rate per minute. Sitting in chamber, cover open.	Rate per minute. Standing in chamber, cover open.	Rate at minutes after walking began. 1′	2′	3′	4′	5′	6′	7′	8′	9′	10′	11′	12′	13′	14′	15′	16′	17′	18′	19′	20′	21′	22′	23′	24′
H. M. S.:																										
Rate	63	71	80	80	80	79	80	81	79	77	80	77	82	80	78	81	80	79	82	80	82	...	81	80	80	80
P. ct. change	...	...	13	13	13	11	13	14	11	8	13	8	16	13	10	14	13	11	16	13	16	...	14	13	13	13
H. W. F.:																										
Rate	65	75	80	...	...	82	...	...	...	...	...	...	...	...	...	90	...	...	...	87	...	83	...	83	...	86
P. ct. change	...	...	7	...	...	9	...	...	...	...	...	...	...	...	...	20	...	...	...	16	...	11	...	11	...	15
E. L. F.:																										
Rate	69	75	87	86	88	78	86	91	91	90	88	87	90	92	94	92	88	87	90	90	88	91	88	88	90	...
P. ct. change	...	...	16	15	17	4	15	21	21	20	17	16	20	23	25	23	17	16	20	20	17	21	17	17	20	...
T. M. C.:																										
Rate	69	78	88	83	82	..	83	82	83	83	80	83	86	82	80	82	83	81	83	86	85	86	83	82	85	...
P. ct. change	...	...	13	6	5	..	6	5	6	6	3	6	10	5	3	5	6	4	6	10	9	10	6	5	9	...
H. S.:																										
Rate	72	80	90	85	85	85	83	87	82	87	85	90	87	94	92	91	...	90	...	93	...	92	...	96	...	...
P. ct. change	...	...	13	6	6	6	4	9	3	9	6	13	9	18	15	14	...	13	...	16	...	15	...	20	...	...
Average	68	76	85	84	84	81	83	85	...	...	...	...	...	87	...	...	...	...	...	...	...	...	...	86	85	
Per cent	...	...	12	...	...	...	...	12	...	...	...	...	...	14	...	...	...	...	...	...	...	...	...	...	12	

Subject.	Standing in chamber, cover open; rate at minutes after walking ceased. 30″	1′	2′	3′	4′	5′	6′	7′	8′	9′	Sitting in chamber, cover open; rate at minutes after sitting. 30″	1′	2′	3′	4′	5′	6′	8′
H. M. S.:																		
Rate	...	...	...	...	...	...	...	...	...	...	71	71	71	69	71	70	71	66
P. ct. change	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
H. W. F.:																		
Rate	71	74	80	86	...	...	...	...	...	...	62	63	63	65	63	65	62	...
P. ct. change	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
E. L. F.:																		
Rate	...	85	83	86	90	90	85	88	83	82	66	65	70	65	62	60	...	...
P. ct. change	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
T. M. C.:																		
Rate	75	76	79	80	80	80	80	80	80	80	71	70	75	71	72	71	71	71
P. ct. change	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
H. S.:																		
Rate	81	81	91	92	85	86	88	91	82	83	67	71	70	71	67	67	65	[1]67
P. ct. change	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Average	76	79	83	86	85	85	84	86	82	82	67	68	70	68	67	67	[2]66	68
Per cent	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

[1]Rate at 7 minutes.

[2]Includes *E. L. F.* at 5 minutes.

records for but 3 of the 5 subjects at the end of 30 seconds of standing after the walking ceased. These three have an average rate of 76 beats which is a fall of 9 beats from the preceding walking average for 4 subjects, and the same as the group average for the preliminary standing period. This rate was not maintained and rose to 79 beats at the end of 1 minute, and to 86 beats by the end of 3 minutes. At the end of 9 minutes, the average rate for *E.L.F.*, *T.M.C.*, and *H.S.* was 82 beats, or 4 beats above the average preliminary standing rate for these same subjects. The sudden rise in rate for *H.S.* between the first and second minutes after walking ceased and an almost equally sudden fall at the eighth minute are to be noted, although no cause can be assigned for these changes. The increase in rate for *H. W. F.* at the end of the second minute may be accounted for by the fact that two members of the staff were discussing a point of the experiment within his hearing.

From the records of the final sitting pulse it is seen that with neither *H.M.S.* nor *T.M.C.* did the rate return to the normal sitting pulse, although observations were continued with *H.M.S.* for 12 minutes. These two men were older than the other normal subjects, and the subjects in Squads A and B, with the exception of *Pec.* The pulse-rates of the other three subjects were below the preliminary sitting pulse at the end of 30 seconds and the average varied but slightly during the subsequent observations. The average sitting pulse for the group had dropped 15 beats from the standing rate by the end of 30 seconds of sitting or 1 beat below the preliminary sitting rate, and this rate varied but 2 or 3 beats during the succeeding 8 minutes. In this respect the 5 normals did not show such deviation from the preliminary sitting rate as did the other groups. It is to be recalled, however, that the pulse-rates of Squads A and B taken after walking were in all cases radial counts after the subject had left the chamber and was sitting in an adjoining room, while the normal subjects sat on a chair placed on the treadmill in the chamber and the pulse was counted by the deflections of the galvanometer string.

By referring to the normal transition curves shown in figure 101,[1] the average pulse-rate for the first 60 seconds of walking may be very closely determined; these averages are as follows: *T.M.C.*, 98; *E.L.F.*, 90; *H.W.F.*, 81; *H.M.S*, 80; and *H.S.*, 91. From table 101 it is seen that the pulse-rates as determined by counting the beats during the first third of the second minute, *i. e.*, "after 1 minute of walking" as stated in the table, are *T.M.C.*, 88; *E.L.F.*, 87; *H.W.F.*, 80; *H.M.S.*, 80; and *H.S.*, 90. This shows a drop between the average pulse-rate for the first 60 seconds and that of the first part of the second minute of 10 beats for *T.M.C.*, 3 beats for *E.L.F.*, 1 beat for *H.W.F.*, 0 for *H.M.S.*, and 1 beat for *H.S.* and, in connection with the curves for the first minute shown in figure 101, indicates that the heart action quickly

[1] See page 436.

reached its maximum and began to moderate during the first minute, continuing the falling rate into the third and fourth minutes as previously pointed out. A further inspection of the curves in figure 101 shows that this slowing of the rate begins probably within 20 seconds after the walking starts, or in other words, that the pulse overshoots at first the rate needed for the exercise to be performed, and after the first 20 seconds begins an adjustment from the higher rate of stimulus to the lower rate of requirement.

In an earlier publication[1] it was stated that a lowering of the pulse-rate was noted with several subjects on the change from standing to walking. These results are not confirmed by the figures of table 101. The fact that the rates during the 15 seconds of standing preliminary to walking, as found from figure 101, are higher than the standing average for the 10 minutes given in table 101, and that the rates of *T. M. C.*, *H. W. F.*, and *H. S.*, after walking 6 minutes (see fig. 101), have fallen to approximately the preliminary standing rates suggests that possibly the earlier observations were unwittingly taken at the points of highest and lowest changes during this transition period. It is evident that these changes have not yet been sufficiently studied and that measurements of the pulse cycles over longer periods than has been done in this study and the elimination, if possible, of the psychical effect incident to the starting of the treadmill must be made.

Table 102 summarizes the walking pulse data presented in the preceding tables, and shows the average pulse-rates for the sitting, standing, and walking observations, the increase in the number of beats, and the percentage deviation from the average preliminary standing pulse of each group. It is seen from this table that for the two normal groups the change in the number of beats per minute on passing from sitting to standing is 8 for the 5 normals and 7 for Squad B normal, and on passing from standing to walking, both groups had an increase of 9 beats. This is a change of 12 per cent in each instance for the 5 normals and of 10 and 11 per cent for Squad B normal. For the two diet squads, the change in the number of beats on passing from sitting to standing is about the same as for the normal groups, but on account of the normally low initial pulse-rate of the diet squads, the percentage changes are slightly higher. During the walking period the increase in the pulse beats per minute is approximately twice as great for Squad B 20-day as for Squad B normal, with increase in an accompanying percentage change. Squad A 120-day does not show as great changes as does Squad B 20-day, but is higher than the normals both in absolute change in number of beats as well as percentage change. The pulse-rate for standing 2 minutes after walking and the final sitting rate do not indicate that any one group had a greater tendency to a delayed return to the normal rate than another. In fact, Squad A

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 85.

TABLE 102.—*Comparison of the average pulse-rates of a group of 5 normal men and Squad B normal with Squad B 20-day and Squad A 120-day diet, while sitting, standing and walking, and standing and sitting after walking.*

Groups of subjects and conditions compared.	Pulse-rate.		Increase over sitting.		Minutes after walking began.											
					1 minute.			6 minutes.			12 minutes.			24 minutes.		
						Increase over standing.			Increase over standing.			Increase over standing.			Increase over standing.	
	Sitting.	Standing.	Beats.	Per cent.	Rate.	Beats.	P. ct.	Rate.	Beats.	P. ct.	Rate.	Beats.	P. ct.	Rate.	Beats.	P. ct.
5 normals....	68	76	8	12	85	9	12	85	9	12	87	11	14	85	9	12
B, normal....	72	79	7	10	88	9	11	85	6	8	85	6	8	89	10	13
B, 20 day diet	46	52	6	13	69	17	33	64	12	23	69	17	33	69	17	33
A, 120 day diet	52	60	8	15	72	12	20	69	9	15	72	12	20	73	13	22

Groups of subjects and conditions compared.	Standing 2 minutes after walking ceased.			Sitting following standing.					
				2 minutes.			7–9 minutes.		
		Increase over preliminary standing.			Increase over preliminary sitting.			Increase over preliminary sitting.	
	Rate.	Beats.	P. ct.	Rate.	Beats.	P. ct.	Rate.	Beats.	P. ct.
5 normals..................................	83	7	9	70	2	3	[1]68	0	0
B, normal..................................	....	......	......	66	−6	−8	[2]67	−5	−7
B, 20 day diet..............................	61	9	17	46	0	0	[3]47	1	2
A, 120 day diet.............................	63	3	5	50	−2	−4	[3]52	0	0

[1]At 8 minutes. [2]At 7 minutes. [3]Average of 8–9 minutes.

after 120 days of low diet and the five normals were both at the average preliminary sitting rate after 8 minutes, while Squad B normal and Squad B 20-day vary from 5 beats below to 1 beat above the preliminary sitting rate.

From the data given in tables 138, 140, and 142, the percentage change in the metabolism between standing and walking as shown by the heat output may be computed. This corresponds to 215 per cent for Squad B normal, 239 per cent for Squad B 20-day diet, and 215 per cent for Squad A 120-day diet, or the increase in the metabolism with walking 70 meters per minute as compared with the metabolism with standing is approximately alike for the normal and diet squads at about 220 per cent. In contrast with this large percentage increase in the metabolism it is seen from table 102 that the pulse-rate increases more nearly 25 per cent for the diet squads and 10 per cent for the normal squads. This contrast between the percentage changes in the pulse-rate and the metabolism which has been noted before in connection with a series of walking experiments and which differ from those found during muscular work on an ergometer[1], will be discussed

[1]Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 85.

in connection with another series of observations in this laboratory, the results of which are being prepared for publication.

In conclusion, as regards the effect of moderate walking upon the pulse-rate of men subsisting on a restricted diet, it may be said that the same relatively low pulse-rate was present during walking as during sitting. Second, the increases of the standing over the sitting pulse-rate were in absolute number of beats and on a percentage basis slightly greater for the diet squads than for the normal groups. Third, the pulse reached a settled rate as quickly and maintained it as uniformly with the diet squads as with the normal groups. Fourth, the return to the rate preceding walking was irregular and does not admit of a statement that one group showed any marked difference from the others.

INFLUENCE UPON PULSE-RATE OF WORK ON BICYCLE ERGOMETER, WITH SPECIAL REFERENCE TO RETURN TO NORMAL.

One of the best indices of general physical condition is supposed to be the rapidity with which the pulse returns to normal after exercise. In connection with the extensive series of observations carried on at the Y. M. C. A. College by Professors McCurdy and Berry, the investigation of Professor Johnson on the pulse-rate after work on a bicycle ergometer had special significance, since our subjects were for most of the time on reduced diet and a control squad was available for normal data. The men rode a bicycle ergometer,[1] at the rate of 80 revolutions per minute for exactly 5 minutes and with a current of 1.35 amperes through the field. Using the data secured in the calibration tests of this ergometer, as published by Benedict and Cady, Professor Johnson has computed that the total amount of work performed by each subject is as follows:

> "When the pedal revolution is 80 per minute and the current 1.35 amperes, the heat produced per revolution is 0.0198 large calorie. In 5 minutes there are 400 revolutions, producing 7.92 calories.[2] The mechanical equivalent of heat is taken as 427.3 kilogrammeters for each calorie. Multiplying, the result is 3,384 kilogrammeters."

This corresponds to 11.3 kilogrammeters per second, and if converted to foot-pounds, equals 81.6 foot-pounds or about one-seventh horsepower. To give some idea of the approximate amount of work performed in common terms, this would be equivalent to the work done by an individual weighing 163 pounds climbing a 6-inch step every second and attaining an elevation of 150 feet in 5 minutes.

Of special importance, however, is the fact that every subject, in both Squads A and B, performed exactly the same amount of work.

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[1] Benedict and Cady, Carnegie Inst. Wash. Pub. No. 167, 1912. (See description of ergometer II, p. 6.)

[2] This amount of external muscular work corresponds to about 1.5 calories, and is thus comparable with the amount of work employed in some earlier experiments. See Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 154.

Indeed, the exertion prior to and immediately following this work was also exactly the same in all cases. Previous to the riding the subject lay upon a table while the basal[1] normal pulse-rate for that day was taken; he then made a few uniform movements in seating himself upon the ergometer; after 5 minutes of riding he immediately lay down upon the table again. The amount of work performed by each subject was therefore exactly the same. This is important in interpreting the differences, not only in the heart rate under the influence of work, but likewise in the return to normal; also the effect of the low diet and resumption of normal diet upon both the total heart rate and on the rate of return to normal. After the subject had returned to the table, the pulse was taken the first 15 seconds of every minute until it reached the normal pulse for the day.

PULSE-RATE BEFORE AND AFTER WORK ON BICYCLE ERGOMETER, SQUAD A.

It is impracticable to reproduce here all of the many observations obtained by Professor Johnson, these numbering several thousand, but a typical day (November 23) has been selected for illustration, on which all members of Squad A took the test. This day likewise repre-sents the period of approximately minimum lying pulse for the entire squad, as well as the minimum body-weight. The data for November 23 are given in table 103. The first pulse column records the average of at least 3 readings prior to work; the remaining values show the pulse-rate in the first 15 seconds of every minute following the work, and are continued until they reach the level before work. Significant features in these records are, first, the very great increase in pulse-rate due to the work, that is, the heart rate increases very greatly from before work, with the subject in the lying position, to immediately after work, with the subject again in the lying position. The greatest increase in table 103 is shown by *Moy* whose heart rate prior to work was 41 and in the first minute after work 116. In many other instances the heart rate is doubled. The headings of the columns indicate the minute when the pulse-rate of each subject returned to the rate prior to work. It will be seen that 4 subjects required 18 or more minutes, but that 6 subjects returned to normal in 5 minutes or less.[2]

In addition to the pulse-rates given for November 23 we have recorded in table 104 the pulse-rates obtained for most of the members of Squad A on one of the last days with reduced diet (January 31, 1918) and on four subsequent days with unrestricted diet. In these four days there were pronounced changes in both body-weight and initial pulse-rate.

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[1] "Basal" for comparison purposes but not minimum, as all values were obtained with food.

[2] The fact that in the experiments of Benedict and Cathcart the pulse after work stayed at a higher level is not at variance with these findings, for it should be pointed out that Benedict and Cathcart's subject worked over one hour instead of 5 minutes, and undoubtedly the metabolism and pulse-rate were stimulated many hours after the cessation of work.

TABLE 103.—*Pulse-rate before and after work on bicycle ergometer—Squad A, subjects in lying position, with food. November 23, 1917.*

Subject.	Body-weight without clothing. (kg.)	Pulse-rate 1 minute before work.	Pulse-rate in successive minutes after work ceased.[1]																			
			1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	11th.	12th.	13th.	14th.	15th.	16th.	17th.	18th.	19th.	20th.
Bro....	55.8	53	93	58	61	61	62	69	62	63	58	58	60	58	58	58	56	61	58	58	58	53
Can....	70.3	45	81	49	47	47	46	47	48	49	49	48	49	48	46	48	49	45	....	....	....	....
Kon....	65.3	37	76	42	37	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Gar....	63.8	53	103	60	53	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Gul....	61.0	42	84	60	46	42	42	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mon...	61.5	57	101	78	64	61	61	58	57	....	....	....	....	....	....	....	....	....	....	....	....	....
Moy...	57.8	41	116	69	53	50	56	51	52	45	48	49	49	45	44	42	43	43	45	42	41	....
Pea....	61.5	40	89	50	45	49	44	44	44	43	42	43	43	43	44	44	42	42	42	41	....	....
Pec....	60.0	36	65	41	39	38	36	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Spe....	56.8	53	92	55	58	53	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Tom...	55.8	60	118	85	77	73	72	76	76	68	72	70	67	68	65	68	66	68	64	61	....	....
Vea....	60.3	40	72	41	41	40	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

[1] Average number of minutes taken to return to normal, 10.1.

TABLE 104.—*Comparison of pulse-rates before and after work on bicycle ergometer with reduced diet and with unrestricted diet—Squad A.*

[Subjects in lying position, with food.]

Subject and dates.	Body-weight without clothing.	Pulse-rate 1 minute before work.	Pulse-rate in successive minutes after work ceased.																			
			1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	11th.	12th.	13th.	14th.	15th.	16th.	17th.	18th.	19th.	20th.
Bro.																						
Reduced diet:	*kg.*																					
Jan. 31	54.8	48	84	52	48	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Unrestricted diet:[1]																						
Feb. 8	58.0	81	120	88	88	88	84	84	81	...	...	...	...	...	...	...	...	...	...	...	...	...
Feb. 11	60.0	76	120	81	85	84	80	84	81	82	85	84	84	76	...	...	...	...	...	...	...	...
Feb. 15	62.5	76	112	85	84	80	85	88	76	...	...	...	...	...	...	...	...	...	...	...	...	...
Feb. 18	61.0	73	105	77	81	85	88	84	80	80	73	...	...	...	...	...	...	...	...	...	...	...
Can.																						
Reduced diet:																						
Jan. 31	70.5	46	81	53	46	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Unrestricted diet:[1]																						
Feb. 8	75.0	62	109	77	74	70	68	70	74	72	72	76	72	70	69	69	70	69	69	62	...	...
Feb. 11	74.8	74	120	88	77	80	80	82	81	78	81	80	78	74	...	...	...	...	...	...	...	...
Feb. 18	77.0	66	108	72	69	66	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Kon.																						
Reduced diet:																						
Jan. 31	62.5	45	86	65	50	53	55	54	49	50	49	45	...	...	...	...	...	...	...	...	...	...
Unrestricted diet:[1]																						
Feb. 8	67.3	82	122	103	100	97	92	92	88	88	90	88	86	86	88	95	90	90	89	85	89	[2]85
Gar.																						
Reduced diet:																						
Jan. 31	64.3	58	112	73	65	65	66	58	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Unrestricted diet:[1]																						
Feb. 8	67.0	66	128	85	80	76	77	78	78	78	77	80	77	78	78	77	76	80	77	74	...	...
Feb. 11	68.5	71	126	88	78	73	76	74	73	76	77	74	74	77	74	71	...	...	...	...	...	...
Feb. 15	69.8	70	126	80	76	76	74	74	73	74	77	70	...	...	...	...	...	...	...	...	...	...
Feb. 18	70.5	66	116	75	69	66	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Gul.																						
Reduced diet:																						
Jan. 31	60.5	46	93	72	53	49	46	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Unrestricted diet:[1]																						
Feb. 8	64.5	80	132	96	93	89	88	88	85	86	86	82	80	...	...	...	...	...	...	...	...	...
Feb. 11	66.0	78	124	93	88	88	85	85	85	84	78	...	...	...	...	...	...	...	...	...	...	...
Feb. 15	65.8	72	124	88	85	81	92	81	80	77	76	80	72	...	...	...	...	...	...	...	...	...
Feb. 18	68.5	80	136	105	100	97	93	88	92	88	86	80	...	...	...	...	...	...	...	...	...	...
Mon.																						
Reduced diet:																						
Jan. 31	60.3	57	93	73	65	65	64	62	66	67	63	61	57	...	...	...	...	...	...	...	...	...
Unrestricted diet:[1]																						
Feb. 8	65.0	82	132	105	100	97	95	93	92	90	86	84	82	...	...	...	...	...	...	...	...	...
Feb. 11	65.5	88	128	104	96	96	93	93	97	92	93	92	93	92	88	...	...	...	...	...	...	...
Feb. 15	67.0	85	128	108	104	101	95	96	92	96	93	93	85	...	...	...	...	...	...	...	...	...
Feb. 18	67.3	80	122	101	96	96	92	92	93	89	84	88	80	...	...	...	...	...	...	...	...	...
Moy.																						
Reduced diet:																						
Jan. 31	57.3	57	109	80	70	65	66	64	62	63	61	61	72	57	...	...	...	...	...	...	...	...
Unrestricted diet:[1]																						
Feb. 8	63.5	77	124	96	85	88	85	82	81	77	...	...	...	...	...	...	...	...	...	...	...	...
Feb. 11	62.0	76	128	93	84	84	84	80	82	81	85	81	81	81	81	78	81	76	...	...	...	...
Feb. 15	65.0	77	118	89	80	81	84	84	81	84	77	...	...	...	...	...	...	...	...	...	...	...
Feb. 18	66.0	76	128	80	80	85	80	80	79	78	76	...	...	...	...	...	...	...	...	...	...	...
Pea.																						
Reduced diet:																						
Jan. 31	61.5	42	96	57	44	42	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Unrestricted diet:[1]																						
Feb. 15	69.8	80	120	84	84	80	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Feb. 18	70.3	84	132	88	84	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Pec.																						
Reduced diet:																						
Jan. 31	59.0	42	76	53	42	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Unrestricted diet:[1]																						
Feb. 8	60.0	60	100	69	60	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Feb. 11	63.5	74	109	86	80	80	82	77	77	80	74	...	...	...	...	...	...	...	...	...	...	...
Feb. 15	64.5	80	109	82	80	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Feb. 18	66.0	88	122	101	97	96	100	93	92	92	92	88	...	...	...	...	...	...	...	...	...	...
Vea.																						
Reduced diet:																						
Jan. 31	59.5	37	89	44	40	40	37	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Unrestricted diet:[1]																						
Feb. 8	59.8	53	90	60	53	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Feb. 11	62.0	76	109	88	84	81	81	81	81	80	80	76	...	...	...	...	...	...	...	...	...	...
Feb. 15	65.3	86	124	100	93	93	92	89	86	...	...	...	...	...	...	...	...	...	...	...	...	...
Feb. 18	65.5	74	116	93	85	90	86	77	84	74	...	...	...	...	...	...	...	...	...	...	...	...

[1] Unrestricted diet began with breakfast, Feb. 3.

[2] *Kon* showed a pulse-rate of 82 at the 21st minute.

From table 104 several important facts may be observed. In the first place, attention is called to the great increase in pulse-rate due to the work on the ergometer, which is shown by the records for the first minute after riding. With one or two subjects with low pulse-rate before work like *Vea*, *Pea*, and *Gul* on January 31, the pulse-rate is more than doubled as a result of the work of riding. In a number of cases the pulse-rate is almost doubled, notably with *Kon*, *Gar*, *Moy*, and *Pec*.

A second important point is the pronounced increase in pulse-rate prior to riding on days with full diet in February which is likewise reflected in the increase noted after the first minute. Coincidental with this is an almost invariable lengthening in the time required for the return to normal.

A more complete analysis of the situation is given in table 105, in which we have summarized for the individual subjects and for each day of Professor Johnson's observations the length of time required for the pulse-rate to return to normal. Although it is somewhat inconsistent to strike a general average, an examination of the average figures for reduced diet near the bottom of table 105 shows that the shortest average period was found with *Vea*, who returned to the normal inside of 4.0 minutes; *Pec* reached normal in 4.3 minutes, *Can* in 5.1 minutes, and *Pea* in 5.9+ minutes. Of these men, *Pea* and *Pec* were trained athletes, while *Vea* and *Can* were distinctly of the non-athletic type. The records shown for *Vea* are of special interest as indicating how regular his return to normal usually was. With the restricted diet there were only three occasions when he required more than 5 minutes to reach the normal level. The one instance in which 10 minutes was required occurred on February 11 after the restriction in diet had ended. On the other hand, with *Tom*, an entirely untrained man, an average value of 16.7+ minutes was obtained for the return to normal, the individual data remaining very long throughout the observations. It is perhaps somewhat surprising that the high values of 13 and 12 were noted with *Kon*, *Mon*, and *Moy*, who were all physically well-trained men. *Mon*, particularly, shows a consistently long time for his return to normal; in only three instances was less than 7 minutes required.

A general inspection of the table seems to indicate that the longer periods for the return to the normal level occur with practically all the men about November 9 to December 7. A consideration of the figures in the last column at the right shows that this is borne out by the daily averages for the whole squad. On the other hand, most of the squad showed a long period of return on February 8 to 18, when the body-weight was rapidly increasing (see table 104) and a greater amount of nourishment was being received than during January, when the men were on a restricted diet and the weight was below normal. The average time for January 31 (a low-diet day) was 6.2 minutes. On

TABLE 105.—*Time required for pulse-rate to return to normal after work on bicycle ergometer—Squad A, subjects in lying position, with food.*

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av. for squad.[1]
1917. Reduced diet:	*min.*	*min.*	*min.*	*min.*	*min.*	*min.*	*min.*	*min.*	*min.*	*min.*	*min.*	*min.*	*min.*
Oct. 19	7	4		10	12	20	9	4	8	8	7	8	9.1
22	3	5		7	15	14	10	4	6	8	17	4	7.6
26	3	3		3	13	5	4	6	4	[2]20	[2]20	4	5.0
29	6	4	8	[2]20	11	18	6	3	4	17	14	4	8.4+
Nov. 2		3		[2]20	[2]20	5	7	4	3	8	12	3	8.1+
5		3	6	[2]20	9	13	18	5	4	2	16	3	9.0+
9	13	4	10	8	16	14	12	6	6	11	[2]20	3	9.2
12	18	3	11	16	7	18	[2]20	7	4	9	20	3	10.7+
16	14		13	16	8	[2]20	[2]20	8		10	[2]20	4	12.9+
19	[2]20	17		3	5	12	15	5	6	6		3	9.6+
23	20	16	3	3	5	7	19	[2]20	5	4	18	4	10.2+
26	4	12	[2]20		[2]20	13	15	6	4	3	[2]20	3	10.8+
Dec. 3	3	3				18	[2]20	4	6	[2]20	[2]20	3	8.1+
7	6	3	[2]20	4	3	18	[2]20	7	3	9	17	7	9.1+
10	10	2	[2]20	3	8	11	9	13	3	11	10	6	8.5+
14	[2]20			3	3	18	[2]20	3	3		[2]20	4	9.3+
17	7	3	4	3	16	20	17	7	3		16	3	8.3
1918. Jan. 7				4			9	4					
11	5	3		5	3	4	11	3	8			3	5.0
14		2	[2]20	3	6	7	14	4	3			3	6.9+
18	3	10	5		7	8	10	9	3			5	6.7
21	3	3	[2]20	3	3	9	4	3	3			3	5.4+
28	3	2		4	10	17	3	2	2			3	5.1
31	3	3	10	6	5	11	12	4	3			5	6.2
Av.	8.6+	5.1	12.1+	7.8+	9.3+	13.0+	12.7+	5.9+	4.3	9.7+	16.7+	4.0	8.3+
Unrestricted diet: Feb. 8	7	18	[2]20	[2]20	11	11	8		3			3	11.2+
11	12	12		14	9	13	15		9			10	11.8
15	7			10	11	11	9	4	3			7	7.7
18	9	4		4	10	11	9	3	10			8	7.5
Av.	8.8	11.3	20.0+	12.0+	10.3	11.5	10.3	3.5	6.3			7.0	10.1+

[1] These averages do not include the values for *Spe* and *Tom*.

[2] More than 20 minutes required for pulse-rate to return to normal; the averages which include these records are indicated by the plus sign.

this day the longest time required for return to normal was shown by *Mon* (11 minutes) and *Moy* (12 minutes). With the resumption of full diet, the time for return to normal increased, being on the average, 11.2 minutes on February 8, 11.8 minutes on February 11, 7.7 minutes on February 15, and 7.5 minutes on February 18. Although the number of men included in the average is not always the same, the figures give a clear indication not only that the time lengthened when the men returned to full diet, but that on the later days in February there was a tendency with most of the subjects for the pulse-rate to return to normal a little more rapidly than during the first days of full diet.

An interpretation of the true effects of the low diet upon the return of the pulse to normal after work is, from the data with Squad A (table 105), extremely difficult. At the period in November and December, when the body-weight was approaching a minimum and the caloric intake was very low, we find some of the highest figures, that is, the longest delayed return to normal. After the return of the men from the Christmas vacation, *i. e.*, during the month of January, the squad as a whole reached a level very considerably lower. The average values for January are, however, vitiated by the fact that both *Spe* and *Tom* were not in the squad and the pulse-rate with both of these men had previously required a long time to return to normal level. The figures for this month are distinctly at variance with those for November and December, and but few direct conclusions can be drawn. The possibility of a training should not be lost sight of. In the absence of clear-cut evidence we can only consider the difference between the return to normal of the pulse-rate during the month of January and that found subsequently after the resumption of feeding. Here the picture is very clear, namely, an increased lengthening of the time required in the latter period, but the situation is also complicated greatly by the ingestion of a large amount of food with pronounced katabolic processes, involving the deposition of fat and a general increase in weight. Unfortunately, as will be subsequently seen, reference to the data obtained with Squad B does not materially clarify the situation.

The correlation between the rapidity of return to normal of the heart rate and the physical condition of man has been especially studied by Pembrey and his associates.[1] His general conclusion is that with the untrained man the return to normal is longer than with the well-trained man. "The pulse of the trained man has a slower rate at rest, a wider range in response to muscular work and a more rapid recovery after exercise."

The picture for *Pea* and *Pec* and the delayed return with the entirely untrained man *Tom* are in full conformity with Pembrey's views, but

[1] Pembrey and Todd, Journ. Physiol., 1908, **37**, Proc. Physiol. Soc., Oct. 17, p. lxvi. Pembrey's work is best summed up in his article with Cook, Journ. Physiol., 1913, **45**, p. 446.

it is difficult to account on this basis for the rapid return to normal of *Vea* and *Can,* who were untrained men, and the delayed action of the well trained men, *Mon, Moy,* and *Kon.*

Pembrey comments further on the reaction to a definite amount of work, which makes of interest an examination of the percentage increase in the pulse of our subjects after the work of riding. It will be remembered that these men were all given a definite amount of work on the bicycle ergometer. We have reproduced in table 106 the values for Squad A for the pulse-rate before work and the first minute after work as found by Professor Johnson, and have added to this the percentage increase in pulse-rate above the basal va'ue obtained with the subject in the lying position before work. Although values for the normal diet period are missing, we have values for February 8 to 18, inclusive, which represent those obtained after the resumption of full diet. Certain of the increments due to work have already been pointed out in the discussion of the data in table 104. In table 106, however, the absolute values for the pulse-rate before and after the riding are given for the whole series of observations, as well as the increases expressed in percentages. Bearing in mind that the amount of work was invariably the same, it can be seen that with approximately constant conditions the percentage increase in pulse-rate as a result of this amount of work varied considerably in the period from October 19 to January 31. With *Bro* it ranged from 44 to 98 per cent, with *Can* from 40 to 96 per cent, and with *Kon* from 69 to as high as 161 per cent. Maximum increments similar to those of *Kon* are found with *Gar* of 150, *Moy* of 183, *Pea* of 153, *Pec* and *Tom* of 124, and *Vea* of 141. Perhaps the greatest difference in increments is that noted with *Moy,* which ranged from 68 to 183 during the low-diet period. There is a general tendency for the larger percentage increases to be observed from November 5 on to the end of the diet period, although this is not invariably the case. With the resumption of diet there is in every case a distinct lowering of the percentage increase due to the work.

An examination of the values for the pulse-rates the first minute after the work shows that during the month of February these are generally somewhat higher than at any other time of the period. Simultaneously there is a very great increase in the basal pulse which more than offsets the increase in the pulse after work, thus lowering the percentage of increase. If we are to interpret Professor Pembrey's conception literally, this "wider range in response to muscular work" noted here would indicate that the lowered diet was distinctly advantageous. It is apparent that on the low diet the response of the heart to the same amount of work is much greater on the basis of percentage of normal than on the full diet.[1]

[1] The greater percentage increase is in large part due to the lower basal values. The actual increase in number of heart beats, as noted during the first minute after work ceased, *i. e.,* an increase based upon values presumably not far from those actually obtaining during work, remains for each subject reasonably constant.

TABLE 106.—*Pulse-rate and percentage increase in pulse-rate following work on bicycle ergometer—Squad A, subjects in lying position, with food.*

Date.	Bro.			Can.			Kon.			Gar.			Gul.			Mon.		
	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.
1917.																		
Reduced diet:																		
Oct. 19	64	96	50	68	108	59	...	...	...	52	124	138	68	120	76	64	112	75
22	64	92	44	52	96	85	...	...	...	56	116	107	62	120	94	68	108	59
26	60	100	67	68	116	71	...	...	...	52	92	77	68	112	65	68	120	76
29	58	92	59	51	100	96	56	101	80	44	97	120	58	100	72	64	116	81
Nov. 2	...	...	...	48	84	75	...	...	...	40	95	138	57	101	77	65	101	55
5	...	...	...	53	74	40	64	108	69	48	107	123	51	90	76	58	105	81
9	56	103	84	50	73	46	41	107	161	45	104	131	47	93	98	53	112	111
12	58	104	79	48	76	58	42	92	119	39	90	131	43	88	105	51	99	94
16	60	119	98	...	...	...	36	85	136	38	95	150	44	85	93	49	96	96
19	45	85	89	49	85	73	...	...	...	50	95	90	53	92	74	65	107	65
23	53	93	75	45	81	80	37	76	105	53	103	94	42	84	100	57	101	77
26	56	81	45	46	81	76	36	76	111	...	...	...	45	95	111	58	103	78
Dec. 3	51	90	76	53	85	60	...	...	...	...	...	...	...	...	...	64	114	78
7	62	101	63	53	84	58	42	97	131	42	92	119	53	85	60	56	109	95
10	63	114	81	60	89	48	49	107	118	49	93	90	53	95	79	74	126	70
14	58	104	79	...	...	...	...	...	...	47	100	113	52	85	63	69	122	77
17	62	108	74	50	79	58	45	100	122	49	99	102	53	100	89	63	112	78
1918.																		
Jan. 7	...	...	...	...	...	...	...	...	...	57	124	118	...	...	...	...	...	...
11	58	93	60	54	93	72	...	...	...	53	112	111	58	99	71	60	96	60
14	...	...	...	53	85	60	54	100	85	49	100	104	53	101	91	66	97	47
18	58	84	45	46	89	93	46	101	120	...	...	...	52	112	115	62	109	76
21	51	77	51	42	80	90	42	93	121	45	92	104	49	99	102	56	103	84
28	49	86	76	49	73	49	...	...	...	42	88	110	44	92	109	54	100	85
31	48	84	75	46	81	76	45	86	91	58	112	93	46	93	102	57	93	63
Unrestricted diet:																		
Feb. 8	81	120	48	62	109	76	82	122	49	66	128	94	80	132	65	82	132	61
11	76	120	58	74	120	62	...	...	...	71	126	77	78	124	59	88	128	45
15	76	112	47	...	...	...	...	...	...	70	126	80	72	124	72	85	128	51
18	73	105	44	66	108	64	...	...	...	66	116	76	80	136	70	80	122	53

Date.	Moy.			Pea.			Pec.			Spe.			Tom.			Vea.		
	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.	1 minute before work.	1 minute after work.	Percentage increase.
1917. Reduced diet:																		
Oct. 19	62	120	94	48	84	75	80	128	60	60	108	80	72	108	50	60	100	67
22	60	108	80	42	84	100	52	100	92	60	104	73	64	132	106	64	100	56
26	62	116	87	48	100	108	52	88	69	72	112	56	68	128	88	64	108	69
29	48	100	108	42	81	93	47	84	79	52	100	92	70	124	77	69	104	51
Nov. 2	70	128	83	41	82	100	40	73	83	61	99	62	61	118	93	66	103	56
5	43	100	133	44	84	91	41	74	80	53	86	62	58	120	107	66	108	64
9	49	115	135	41	85	107	37	78	111	45	79	76	56	123	120	58	95	64
12	40	99	147	36	91	153	38	83	118	58	105	81	60	122	103	64	104	63
16	41	107	161	34	76	124	......	......	......	69	114	65	59	132	124	38	72	89
19	36	96	167	39	84	115	34	76	124	46	83	80	......	......	......	45	90	100
23	41	116	183	40	89	123	36	65	81	53	92	74	60	118	97	40	72	80
26	38	107	182	38	85	124	41	81	98	61	100	64	67	132	97	42	84	100
Dec. 3	45	101	124	42	85	102	47	77	64	56	108	93	78	144	85	50	96	92
7	43	112	160	36	77	114	42	81	93	53	88	66	58	109	88	35	69	97
10	53	120	126	42	97	131	41	80	95	58	105	81	63	122	94	41	84	105
14	45	108	140	40	81	103	48	92	92	......	......	......	62	128	106	36	72	100
17	49	116	137	42	96	129	47	81	72	......	......	......	63	116	84	37	70	89
1918.																		
Jan. 7	74	124	68	48	100	108	......	......	......	......	......	......	......	......	......	......	......	......
11	44	100	127	46	96	109	46	88	91	......	......	......	......	......	......	56	101	80
14	49	111	127	56	104	86	49	88	80	......	......	......	......	......	......	48	85	77
18	46	105	128	48	99	106	53	84	58	......	......	......	......	......	......	34	65	91
21	39	96	146	41	86	110	42	80	90	......	......	......	......	......	......	32	60	88
28	42	93	121	45	81	80	45	76	69	......	......	......	......	......	......	36	65	81
31	57	109	91	42	96	129	42	76	81	......	......	......	......	......	......	37	89	141
Unrestricted diet:																		
Feb. 8	77	124	61	......	......	......	60	100	67	......	......	......	......	......	......	53	90	70
11	76	128	68	......	......	......	74	109	47	......	......	......	......	......	......	76	109	43
15	77	118	53	80	120	50	80	109	36	......	......	......	......	......	......	86	124	44
18	76	128	68	84	132	57	88	122	39	......	......	......	......	......	......	74	116	57

PULSE-RATE BEFORE AND AFTER WORK ON BICYCLE ERGOMETER, SQUAD B.

Although Professor Johnson rightly laid special emphasis upon the values obtained with Squad A, those for Squad B also have a special significance, owing to the fact that they present a large number of normal values for comparison with those obtained during the short period of reduced diet. The values for Squad B are recorded in detail in table 107, in which is given for each subject the pulse before the experiment, the pulse one minute after riding, the percentage increase, and the number of minutes required for the pulse to return to normal. With two subjects, *Kim* and *Sch*, the early basal values are missing, although we have one or two post-diet values with each of these subjects. The pulse-rate prior to riding has been discussed in connection with table 85 (see page 400) and with Squad B shows the usual fall during the period of restricted diet. Since no pulse values previous to the reduction in diet were obtained with Squad A, a special significance of the results in table 107 must be the relative constancy of the basal values, *i. e.*, the normal values obtained outside the low-diet period. When the change was made to a restricted diet, there was a characteristic decrease in pulse-rate, the significance of which has been previously discussed. Squad B shows on the resumption of unre-

TABLE 107.—*Percentage increase in pulse-rate and time required to return to normal after work on bicycle ergometer—Squad B, subjects in lying position, with food.*

Date.	Fis.				Har.				How.				Ham.			
	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.
1917.																
Normal diet:																
Oct. 24	64	100	56	2	64	128	100	12	72	128	78	10	72	92	28	2
31	61	101	66	4	74	140	89	8	62	105	69	3	58	89	53	2
Nov. 7	60	103	72	2	65	122	88	16	60	100	67	15	60	100	67	14
14	60	101	68	4	70	136	94	13	66	103	56	2	65	108	66	2
21	54	90	67	4	53	120	126	10	77	119	55	8	69	105	52	3
Dec. 5	....	....	....	....	67	128	91	12	70	116	66	10	63	101	60	4
12	....	....	....	....	54	122	126	10	68	120	76	3	58	101	74	6
1918.																
Reduced diet:																
Jan. 9	....	....	....	....	....	....	....	....	66	118	79	15	61	105	72	4
16	58	103	78	2	49	111	127	7	57	97	70	3	61	99	62	2
23	49	99	102	3	45	122	171	20[1]	58	108	86	2	54	95	76	2
Unrestricted diet:																
Jan. 30	....	....	....	....	66	124	88	6	65	112	72	13	72	109	51	4
Feb. 6	....	....	....	....	77	128	66	7	92	132	43	7	66	104	58	7
13	76	118	55	5	69	124	80	8	82	128	56	15	73	108	48	3
20	50	93	86	8	70	126	80	6	85	132	55	9	58	101	74	4

[1]More than 20 minutes required for pulse-rate to return to normal.

TABLE 107.—*Percentage increase in pulse-rate and time required to return to normal after work on bicycle ergometer—Squad B, subjects in lying position, with food*—continued.

Date.	Kim.				Lon.				Sch.				Liv.			
	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.
1917.																
Normal diet:																
Oct. 24	....	....	....	....	60	116	93	11	....	....	....	....	68	112	65	15
31	....	....	....	....	60	104	73	7	....	....	....	....	56	97	73	7
Nov. 7	....	....	....	....	62	116	87	15	....	....	....	....	60	112	87	4
14	....	....	....	....	53	112	111	5	....	....	....	....	61	103	69	3
21	....	....	....	....	58	107	84	8	....	....	....	....	62	114	84	3
Dec. 5	....	....	....	....	63	109	73	3	....	....	....	....	62	112	81	6
12	....	....	....	....	....	....	....	....	....	....	....	....	54	100	85	18
1918.																
Reduced diet:																
Jan. 9	....	....	....	....	54	107	98	13	....	....	....	....	58	96	66	4
16	66	101	53	16[1]	49	88	80	3	38	85	124	7	44	88	100	14
23	58	101	74	12	....	....	....	....	38	67	76	3	49	84	71	5
Unrestricted diet:																
Jan. 30	....	....	....	....	60	120	100	18	53	99	87	3	62	132	113	4
Feb. 6	77	112	45	3	69	122	77	9	64	100	56	2	71	122	72	7
13	....	....	....	....	70	118	69	4	....	....	....	....	68	118	74	4
20	84	120	43	13	75	126	68	3	....	....	....	....	65	122	88	3

Date.	Sne.				Tho.				Van.				Wil.			
	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.	1 minute before work.	1 minute after work.	Percentage increase.	Minutes to return to normal.
1917.																
Normal diet:																
Oct. 24	68	132	94	12	60	124	107	16	64	92	44	8	64	108	69	9
31	68	124	82	11	58	89	53	5	58	84	45	8	65	107	65	9
Nov. 7	76	128	68	4	56	84	50	2	61	90	48	8	65	118	82	3
14	74	124	68	3	57	96	68	3	58	92	59	3	64	109	70	5
21	....	....	....	....	59	101	71	2	62	101	63	12	57	108	89	7
Dec. 5	72	148	106	15	56	100	79	4	58	86	48	2	69	122	77	2
12	76	132	74	7	52	89	71	3	....	....	....	....	60	120	100	4
1918.																
Reduced diet:																
Jan. 9	67	122	82	7	50	85	70	3	62	116	87	12	58	120	107	11
16	58	118	103	8	46	73	59	2	46	73	59	3	52	96	85	3
23	54	118	119	18	44	72	64	2	37	86	132	5	40	89	123	3
Unrestricted diet:																
Jan. 30	78	120	54	3	56	88	57	2	53	95	79	3	61	108	77	3
Feb. 6	....	....	....	....	56	93	66	2	62	104	68	13	64	120	88	7
13	....	....	....	....	54	100	85	3	76	101	33	3	69	118	71	4
20	....	....	....	....	....	....	....	....	63	101	60	10	70	124	77	7

[1]Pulse-rate was 72 at the end of 16 minutes; no further records obtained.

stricted diet increases in basal pulse prior to work similar to those exhibited by members of Squad A, although it is worth while to note that in certain instances, at least, such as with *Fis* on February 20 and with *Ham* on the same date, relatively low basal pulse values are recorded, even after three weeks of unrestricted diet.

It is, however, more particularly with the reaction to work that we are concerned in this discussion, and the reaction of the pulse-rate to work is with this squad especially interesting as it shows what may be expected for increased pulse-rate with a constant amount of work under normal diet. Thus, during the period with normal diet, the values for *Fis* are fairly close to 66 per cent. With *Har* the values range from 88 to 126 per cent. With the other subjects the ranges are usually reasonably uniform, although *Ham* shows a range of from 28 to 74, and *Tho* an unusual range of 50 to 107. With nearly all subjects, the two or three observations during restricted diet show a distinct tendency for the percentage increase to rise.

As pointed out in discussing the results for Squad A (see page 461, footnote 1), this increase in the percentage increment following work is in considerable part due to the lower basal value, although the absolute increments are not so regular as those found with Squad A. Here we have unquestionably the complicating circumstance of a diet furnishing but approximately one-third of the requisite number of calories, with severe drafts upon body material.

Considering the length of time required for the pulse-rate to return to normal, we find again wide differences among the men. Thus with *Fis*, and usually *Ham*, *Sch*, *Tho*, and *Wil*, most of the values are very low, while with *Har*, *Kim*, *Lon*, and *Sne* large values are the rule.

It so happens that of the men in squad B whose records appear in table 107, but three of them were taking the secretarial course, *Kim*, *Sne*, and *Tho*. *Tho*, after the first two days, had remarkably low values for the time required to return to normal. There is, however, little in this table which throws light upon the point raised by Pembrey in regard to the fitness for physical training and the facilitation of heart action, as indicated by the rapidity of return to normal pulse.

With normal diet the same individual with the same amount of work had approximately the same percentage increase. One must bear in mind the striking exceptions pointed out in an earlier paragraph, especially in the case of *Ham*, whose percentage increase ranged from 28 to 74 per cent, and of *Tho* whose increase varied from 50 to 107 per cent. In general the return to normal was reasonably uniform with a given individual. An inspection of these data shows no marked influence of the restricted diet upon the length of time required to return to normal, this not being markedly greater than with normal diet. It does happen, however, that a large number of the lowest values occur in the period of restricted diet and to this degree the results confirm the

observations made with Squad A, in which the basal values with low diet obtained during January, when compared with those obtained during February with an unrestricted diet, showed a tendency for a more rapid return to normal of the pulse-rate following a definite amount of physical work.

CONCLUSIONS REGARDING PULSE-RATE.

In this section we have endeavored to present as complete a picture as possible of the changes in pulse-rate level occasioned by the low diet with the accompanying change to a lower nutritional plane. We have presented data for the basal pulse-rate with the subjects in the lying position and with the subjects in the same position before riding the bicycle ergometer, with the subjects sitting and standing, and engaging in short periods of muscular exertion, also beginning to walk on the treadmill, during a prolonged period of walking, the transition following walking, and, finally, the recovery to the normal pulse-rate following a standard amount of work on the bicycle ergometer. The data have been presented analytically in each case and compared with the normal standard. This normal standard is rather fragmentary in the case of Squad A but fairly satisfactory for Squad B; in some cases there are other normals with which we could compare these low-diet pulse-rates.

It would appear as proved by the standard electrocardiograms that the lower pulse-rate characteristic of the low diet is not accompanied by any pathological changes but is a simple difference in the pulse-rate level between the condition of uncontrolled eating and the reduced diet. The actual values for the pulse-rate during rest are such as have never heretofore been observed with normal man, for a considerable number of men showed pulse-rates of 35 and below and one subject gave positive evidence of a rate of 29 on at least one day. Not only was the pulse-rate per minute very perceptibly reduced by the low diet, but the blood pressures have also been shown to be distinctly lower during the same period. (See p. 382.) These low blood pressures following diet restriction with both Squads A and B, taken in connection with the low pulse-rates, show clearly that the work of circulation of these men made a minimum demand on metabolic activity. We thus find here a most economically working heart, at least under normal conditions of rest.

During short periods of work, as in "chinning the bar" (p. 415), the percentage increase occasioned by this physical exercise was practically the same for normal men and for those on the low diet, that is, there was a simple change in pulse-level for the resting, working, and recuperation pulse with these short periods of work, *i. e.*, periods less than one-half minute in length. With the pulse during work, judged according to the standards which we have, it seems clear that the men on reduced diet showed a greater percentage increase, as, for example,

for the first minute of walking, over the level of the standing pulse, than the men on normal diet did. Following the bicycle riding it seems that the increase occasioned by the riding was slightly greater for normal than for reduced diet subjects; the only difference was that with the latter men there was a tendency to a quicker return to the normal base line. All in all, therefore, it seems that the pulse for the reduced diet condition demonstrates this difference, *i. e.*, a lowering in the level without discoverable modification in the functional efficiency of the heart rate to meet the needs of the circulation of the organism under the varying conditions of rest and activity.

RESPIRATION RATE.

Throughout the entire series of experiments with both the portable respiration apparatus and the respiratory-valve apparatus, the respiration rate was obtained graphically by means of a pneumograph placed around the chest of the subject. Certain respiration rates were likewise determined on the morning of the standing respiration experiments prior to walking by noting the rise and fall of the spirometer bell. These were counted in definite periods of time and were recorded by the observer. All the respiration rates observed in this series of experiments were obtained when the subject was attached to some form of breathing appliance. With the portable respiration apparatus, for both the lying and the standing positions, the regulation mouthpiece and nose-clip were used. With the respiratory-valve apparatus a mask was attached to the face; with this, in all probability, a more normal respiration was obtained. Although it was the opinion of the observers that relatively slight, if any, changes in respiration rate were apparent throughout the entire series of tests, we have had all these records carefully inspected and counted and the values obtained on the different mornings are presented in table 108. Since the respiration rate likewise has specific value in the computation of the alveolar air and the amount of air expired per respiration, certain respiration rates also appear in table 111. (See p. 480.)

COURSE OF RESPIRATION RATE WITH REDUCED DIET.

Making due allowance for the novelty of the experiment and the necessity for getting used to the breathing-appliance attachment in the first few days, namely, during the normal diet, no striking difference between the rate with normal diet and that in the first few days of reduced diet can be observed in the majority of instances. As the research progressed, however, it can be seen that there was a distinct tendency with a number of the subjects, especially towards the end, for the respiration rate to decrease somewhat. Thus with *Bro* we find a tendency for the level to be somewhat above 13 respirations per minute in the early part of the experiment, but during the

TABLE 108.—*Daily respiration rate—Squad A, post-absorptive and in lying position.*

Date.	Bro.	Can.	Fre.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Daily average.
Normal diet:														
Sept. 27	....	12.7	....	....	11.1	....	....	....	....	....	....	....	....	....
28	12.6	....	20.0	....	....	....	....	....	....	....	....	....	....	....
Oct. 29	11.8	....	....	....	....	....	15.5	....	19.9	....	....	....	....	....
1	....	14.4	20.6	....	14.7	10.4	....	12.2	....	....	....	....	....	14.5
2	....	12.8	18.7	....	14.5	....	15.6	13.0	....	....	10.5	....	12.2	13.9
3	19.4	....	21.6	....	....	8.4	....	13.9	....	13.2	....	14.1	12.4	14.7
4	15.6	12.0	23.1	....	13.4	....	16.2	....	18.1	....	12.9	....	12.4	15.5
Reduced diet:														
Oct. 5	12.6	12.5	20.0	....	14.2	10.2	15.6	....	....	14.9	....	11.1	....	13.9
6	....	....	....	....	....	....	14.7	....	16.0	....	13.5	12.2	11.8	13.6
7	....	....	....	....	....	11.0	....	13.3	....	....	13.9	14.4	11.9	12.9
8	15.2	13.1	21.9	....	13.4	11.9	15.3	....	18.0	....	12.4	....	10.6	14.6
9	....	....	25.2	....	14.0	12.0	16.9	28.8	....	14.9	....	13.1	....	15.6
10	....	13.0	....	....	12.7	....	16.3	12.2	17.9	16.1	....	....	....	14.7
11	13.7	....	19.7	....	....	11.8	....	11.8	17.7	16.3	....	....	....	15.2
12	....	....	....	....	....	....	14.6	....	16.3	....	11.6	....	13.3	14.0
13	13.8	13.3	21.5	....	14.0	13.8	....	12.5	....	....	....	....	....	14.8
15	....	14.0	....	....	13.5	....	13.5	....	18.4	13.9	....	15.2	13.8	14.6
16	13.6	....	23.4	....	....	13.2	....	12.2	....	....	10.7	14.2	12.3	14.2
17	....	13.3	....	....	12.0	....	14.4	....	17.3	13.0	10.4	....	13.0	13.3
18	....	....	21.5	....	....	....	....	12.4	....	13.4	11.0	....	....	14.6
19	....	12.8	....	....	13.2	....	16.3	12.0	....	....	11.3	....	12.4	13.0
20	14.3	....	22.8	....	....	....	....	11.4	....	....	....	13.5	....	15.5
21	....	12.7	....	....	12.2	....	12.7	11.8	....	....	....	....	12.2	12.3
22	....	....	....	....	....	10.2	....	12.1	....	16.7	....	14.4	....	13.4
23	....	....	....	....	12.1	....	14.6	....	17.1	....	10.3	....	11.1	13.0
24	12.8	....	....	....	13.1	11.9	14.0	12.7	....	13.6	....	14.0	....	13.2
25	14.0	12.5	....	....	13.4	....	15.7	....	16.1	....	10.9	....	10.2	13.3
26	12.6	....	....	....	....	....	....	....	....	13.5	....	14.6	....	....
27	13.4	....	....	12.7	12.8	....	....	....	18.1	....	15.7	15.1	13.1	14.4
29	....	....	....	12.9	....	....	....	....	....	13.1	....	14.1	14.0	13.5
30	13.9	....	....	12.4	22.6	....	14.0	12.4	....	14.4	10.7	....	13.0	14.2
31	13.2	13.0	....	....	14.7	8.8	....	....	18.6	....	12.4	12.5	....	13.3
Nov. 1	....	....	....	....	12.3	....	....	....	....	....	11.2	....	....	....
2	....	....	....	14.9	....	....	....	....	....	12.0	....	....	....	....
3	....	....	....	....	....	....	12.4	....	14.1	....	....	....	....	....
4	13.4	11.4	....	17.2	11.5	13.6	....	11.3	....	....	....	....	....	13.1
5	....	12.0	....	....	12.8	....	....	11.6	16.8	14.1	12.5	13.4	14.5	13.5
6	....	....	....	12.5	....	13.4	....	....	15.0	12.1	11.3	....	12.0	12.7
7	12.8	11.1	....	17.4	12.7	12.6	....	....	16.5	....	11.0	....	....	13.4
8	12.1	....	....	12.4	....	....	12.1	12.2	15.1	15.2	....	13.3	....	13.2
9	....	11.2	....	....	12.0	....	12.1	12.1	15.1	11.8	....	11.8	12.1	12.3
10	14.7	....	....	11.6	....	11.3	....	13.1	16.6	14.2	12.8	12.7	12.5	13.3
12	13.7	12.2	....	17.4	12.5	16.6	15.8	....	....	....	10.4	....	13.6	14.0
13	12.2	11.4	....	16.9	12.3	14.5	15.5	10.6	....	12.2	....	10.8	....	12.9
14	....	12.0	....	....	12.1	....	16.7	11.9	15.2	15.0	10.3	13.3	11.9	13.2
15	11.4	....	....	15.3	....	14.8	....	12.1	15.2	16.0	11.1	....	13.8	13.7
16	13.2	11.7	....	15.2	13.0	13.0	14.5	....	13.0	....	11.1	....	12.4	13.0
17	15.6	11.8	....	14.9	12.8	12.9	17.6	12.0	....	13.4	....	11.6	....	13.6
18	....	11.6	....	....	12.0	....	13.3	12.5	15.5	14.0	10.9	13.4	10.8	12.7
19	11.5	....	....	17.7	....	12.4	....	12.4	13.6	12.0	10.0	11.8	11.5	12.5
20	12.7	11.6	....	....	10.8	....	17.2	....	14.8	....	10.1	....	11.9	12.7
21	12.3	12.9	....	12.0	13.4	14.1	16.6	11.9	....	12.8	....	12.0	....	13.1
22	....	11.4	....	....	14.3	13.9	14.5	13.4	14.5	....	10.0	12.6	12.8	13.0
23	13.9	....	....	15.6	....	12.8	14.8	11.8	15.7	13.2	9.9	....	12.9	13.4
24	13.0	11.3	....	15.7	13.5	....	....	....	13.2	14.5	10.6	12.6	10.7	12.8
26	13.1	11.5	....	....	....	18.1	14.0	11.9	....	12.3	....	11.6	....	13.2
27	....	12.0	....	....	....	13.9	16.0	....	....	....	9.8	11.2	11.9	12.5
28	11.3	....	....	13.6	11.6	14.5	....	9.1	14.7	13.1	9.9	....	12.7	12.3

TABLE 108.—*Daily respiration rate—Squad A, post-absorptive and in lying position*—continued.

Date.	Bro.	Can.	Fre.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Daily average.
(Thanksgiving recess.)														
Reduced diet—*con.*														
Dec. 3	12.7	11.2	....	....	....	13.7	12.6	....	14.5	....	9.7	....	11.4	12.3
4	11.4	7.4	....	....	13.1	13.4	....	11.0	15.2	12.4	....	12.6	10.0	11.8
5	....	11.2	....	13.4	12.3	....	15.6	....	....	13.3	....	12.3	12.1	12.9
6	11.6	....	....	15.1	....	....	16.6	....	16.3	11.3	9.8	11.9	....	13.2
7	14.7	11.5	....	12.3	....	....	16.4	....	13.7	....	9.8	....	11.8	12.9
8	12.5	11.3	....	....	11.9	13.1	15.7	10.1	....	12.5	9.8	10.9	....	10.9
10	....	11.6	....	....	13.6	....	13.9	13.3	13.4	15.2	10.3	14.1	13.4	13.2
11	12.4	....	....	....	....	11.9	....	11.1	14.8	....	9.6	12.5	10.4	11.8
12	....	11.7	....	15.4	11.7	13.3	14.3	....	14.6	11.4	....	....	11.4	13.0
13	12.2	10.9	....	....	10.8	10.8	13.2	10.6	13.9	....	....	12.5	....	11.9
14	....	12.4	....	....	10.7	....	14.3	10.7	15.7	13.9	....	12.7	11.7	12.8
15	12.2	....	....	15.7	....	13.1	....	....	....	....	....	12.6	11.6	13.0
16	10.1	12.0	....	....	12.2	....	13.2	10.0	13.0	....	....	....	10.8	11.6
17	....	11.7	....	14.0	11.2	....	13.9	....	....	13.4	....	13.2	....	12.9
18	12.1	11.6	....	....	11.4	13.0	14.9	....	....	....	....	....	12.2	12.5
19	13.7	....	....	15.0	....	12.9	....	11.2	15.5	11.4	....	13.0	12.9	13.2
Christmas recess.)														
Jan. 7	....	12.0	....	....	12.3	11.6	16.9	....	15.4	12.4	....	....	....	13.4
8	....	....	....	....	....	....	....	11.8	13.3	13.0	....	....	13.0	12.8
9	12.3	13.4	....	....	12.4	13.6	....	12.0	....	12.7	....	....	11.8	12.6
10	....	11.1	....	....	11.3	13.5	12.1	12.2	14.9	....	....	....	....	12.5
11	12.8	11.9	....	....	....	....	13.1	12.6	....	13.0	....	....	13.1	12.8
12	14.2	11.8	....	14.7	....	....	....	....	13.8	....	....	13.1	....	13.5
14	....	....	....	14.6	13.5	14.2	12.0	....	....	....	....	13.7	12.2	13.4
15	11.5	11.5	....	15.9	....	....	....	....	....	....	....	....	....	....
16	12.3	12.4	....	....	....	....	....	10.6	15.3	13.0	....	13.2	12.7	12.8
17	....	....	....	17.3	11.9	12.7	11.8	11.5	13.7	12.2	....	....	....	13.0
18	11.8	12.1	....	15.9	12.8	14.0	....	....	....	....	....	13.2	10.9	13.0
19	12.2	13.0	....	15.9	....	....	14.9	10.6	13.3	....	....	....	10.6	12.9
20	....	....	....	....	12.5	10.2	14.5	11.2	14.1	....	....	12.4	....	12.5
21	12.3	12.3	....	....	....	12.8	14.8	....	....	11.7	....	13.0	11.3	12.6
22	....	11.4	....	15.0	11.1	....	....	10.4	15.3	11.4	....	13.3	....	12.6
23	11.7	....	....	15.0	10.7	....	17.3	....	....	....	....	13.3	12.1	13.4
24	11.5	....	....	16.6	....	....	....	11.8	14.3	12.1	....	....	10.9	12.9
25	....	....	....	....	12.7	13.4	12.2	10.3	14.0	11.9	....	13.1	....	12.5
26	11.6	11.5	....	11.9	11.5	13.9	14.0	....	....	....	....	....	10.1	12.1
28	....	....	....	....	....	....	....	9.9	15.1	11.8	....	11.9	....	12.2
29	12.0	11.5	....	13.8	11.9	....	....	....	....	12.3	....	12.1	10.0	11.9
30	11.6	11.0	....	....	....	13.7	14.4	10.6	13.8	....	....	....	11.0	12.3
31	....	....	....	15.4	13.0	14.3	....	....	....	....	....	....	....	....
Feb. 1	12.4	....	....	....	13.0	11.0	12.7	....	14.0	....	....	13.9	12.2	12.8
2	12.2	11.5	....	11.3	....	....	....	....	....	12.5	....	13.8	11.3	12.1

month of January there is a tendency for the rate to be somewhat under this. With *Can* the rate is at first approximately 13 or thereabouts per minute, and during January it is on the average under 12 per minute. With *Kon* irregularity may be noted, particularly at the beginning, but unlike most of the subjects, his respiration rate shows a tendency to increase toward the end of the experiment. With *Gar* a respiration rate approximating 13 or 13.5 per minute at the start slows down to about 12.5 in January. With *Gul* considerable variation is seen at the start, with a tendency for a slight rise in

January. With the values for *Mon* there is no noticeable persistent change throughout the experiment. With *Moy* a slight fall of less than 1 respiration per minute is noted at the end of the experiment. One of the most pronounced changes in respiration rate is found with *Pea*, who, in the early part of the experiment, shows rates approximately 17 per minute, but during January the rate fell to nearly 14. With *Pec* values averaging somewhat above 14 are noted in early October, and in January the rate is about 12 per minute.

In spite of the fact that *Spe* was one of the best subjects that we had for the respiration-apparatus experiments, showing very regular breathing and almost invariably giving very concordant results, we find the respiration rate is irregular. There is a tendency, however, for the lowest values to appear during the months of November and December. His respiration rate per minute was one of the slowest of those recorded.

With *Tom* the general average level is not far from 14 at the start of the experiment, and settles down to about 13 in January. With *Vea,* except between October 27 and November 15, when the respiration rate was somewhat above 13, the rate remained most of the time between 10.5 and 12. In the latter part of January the values average very closely to the rate in the first few days of reduced diet.

With Squad A, therefore, the general picture of the respiration rate shows a slight tendency for the values to decrease somewhat from a group average of not far from 14 in October to 12.5 in January. Careful inspection of the data indicates no appreciable difference in the respiration rate, whether the subject used the mouthpiece on the portable respiration apparatus or the mask with the respiratory-valve apparatus. Table 108 gives the respiration rates for the subjects in the post-absorptive condition and in the lying position, but does not include respiration rates found with the standing position just prior to walking; these will be given in a subsequent table.

It appears very clear from an examination of the averages in the last column of table 108 that no pronounced effect upon respiration rate is to be observed as a result of the restricted diet. In the majority of instances there is a slight decrease in the respiration rate. In one or two cases there is a perceptible increase. Considering the fact that all these respiration rates were obtained with artificial breathing appliances, one may not state positively that there is a general tendency for the reduced diet to alter the respiration rate by more than one or two respirations per minute.

CHARACTER OF THE RESPIRATION.

It is somewhat unfortunate that graphic tracings of the exact respiratory ventilation could not have been obtained, such as are usually secured with the universal respiration apparatus in this Laboratory. Subsequent experience with the portable respiration apparatus has

shown that such graphic records are possible, but since they were not obtained in this research, we must rely solely upon the pictures given by the pneumograph about the chest. It is impracticable to reproduce here the many pneumograph records obtained in connection with these experiments. Careful inspection of the records, however, shows no obvious alteration in the character of the respiration. There is no tendency towards apnoea or dyspnea, nor, so far as the pneumograph tracings indicate, any alteration in the character or type of respiration.

AVERAGE RESPIRATION RATE.

Since the reduced diet had but a slight effect upon the respiration rate, the fact that the average rate with these men was perceptibly lower than that ascribed to normal subjects of their age[1] has no special significance other than to indicate that in all probability the men were well trained, were very little disturbed by the experimenting, and had fullest confidence in the observers. The average respiration rate, even before the reduced diet began, was not far from 14 per minute, a rate which agrees with that found in this Laboratory for men studied under the same normal conditions in an extensive comparison of respiration apparatus, *i. e.*, 14.4 per minute.[2] Subsequent discussion will show that the amount of carbon dioxide to be removed per minute by the ventilating current of air passing through the lungs was lowered nearly one-third as a result of the experimental conditions, and it may at first sight seem rather significant that the respiration rate was not lowered more than 1 or at most 2 respirations per minute with the average subject.

The respiration rate of the man who fasted 31 days[3] had a distinct tendency to rise during the prolonged period of fast. The only other data we have which are at all comparable are those reported by Loewy and Zuntz.[4] The extraordinarily low respiration rate of Zuntz, which averaged 5.4 respirations per minute in 5 experimental periods on three different days, can be compared with his respiration rate as noted in earlier experiments. A careful examination of these experiments shows that there was a tendency for his respiration rate prior to the war to be perceptibly above 7, although occasional instances of 5.5 are noted. The average respiration rate reported for Loewy during the war of 10.6 per minute is perceptibly lower than most of those noted with our subjects, and, indeed, than the occasional ante-bellum rates for Loewy found in his earlier experiments. It is fairly clear that in all cases, including not only our experiments in this research but those of

[1] See Quetelet, Tigerstedt's Lehrbuch der Physiologie des Menschen, Leipsic, 1913, **1**, 7th ed., p. 451.

[2] Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915; also Carpenter, Proc. Nat. Acad. Sci., 1915, **1**, p. 602.

[3] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 163.

[4] Loewy and Zuntz, Berl. klin. Wochenschr., 1916, **53**, pp. 826 and 828.

Zuntz and Loewy, there is a tendency for the respiration rate to be somewhat lower with a low diet. This is in direct contrast with the tendency to an increased respiration rate noted with the fasting man.

RESPIRATION RATE WITH THE STANDING POSITION.

Aside from the regular records of the respiration rates made in the morning respiration experiments on either the respiratory-valve apparatus or the portable respiration apparatus, a few observations were obtained with the men in the standing position. These were with Squad A on February 3, prior to walking, and with Squad B on both January 6 and 28, prior to walking, and are given in table 109. The values for Squad A for February 3 prior to walking range from 10 with *Vea* to 19 with *Mon*. If one compares these with the values obtained in the morning experiments, with the subject lying, on the last three days of the research (see table 108), it will be seen that occasionally the respiration rate for standing differed considerably from that for lying on the previous days. In certain cases, notably with *Can* and *Mon*, decided increases were observed for the standing position. The general average respiration rate for the morning of February 3 is 13.3 per minute for the 11 men.

For Squad B we have two sets of observations, with, however, no observations in the lying position for comparison. (See table 109.)

TABLE 109.—*Respiration rate of subjects, post-absorptive and in standing position. Portable respiration apparatus.*

Squad A.		Squad B.			
Feb. 3, 1918, reduced diet.		Jan. 6, 1918, normal diet.		Jan. 28, 1918, reduced diet.	
Subject.	Respiration rate.	Subject.	Respiration rate.	Subject.	Respiration rate.
Bro.......	12	Fis......	11	Fis......	9
Can......	15	Har	12	Har......	9
Kon......	11	Ham.....	21	Ham.....	22
Gar......	13	Kim.....	14	Kim.....	11
Gul......	11	Sch......	15	Sch......	13
Mon.....	19	Liv......	18	Liv......	22
Moy.....	11	Sne......	22	Sne......	23
Pea......	15	Tho......	10	Tho......	8
Pec.......	15	Van......	14	Van......	11
Tom.....	14	Wil......	22	Wil......	21
Vea......	10	McM....	13	Lon......	13

Here we must confine ourselves to a comparison between the respiration rate for the normal and for the reduced diet. The respiration rates are, in a number of instances, considerably higher than usual. Thus on the day with normal diet we have rates of 21 or over with *Ham*, *Sne*, and *Wil*. On the day with reduced diet the respiration rate had a tendency in a majority of instances to be somewhat lower

than it was on the normal day. Thus with all but *Ham*, *Liv*, and *Sne*, slight falls in the respiration rate occur at the end of the reduced-diet period. The three subjects named show positive rises, particularly *Liv*. Since *Lon* was not at the Laboratory on the normal day (January 6) we have for him only a record for reduced diet. The respiration rate on this day was not far from the average found with Squad A, but distinctly lower than that found with most of the other men in Squad B. The three very low rates of 9, 9, and 8 with *Fis*, *Har*, and *Tho* at the end of the reduced-diet period have special interest. These are lower than any rates observed with Squad A in the standing position and even lower than those observed with the men of Squad A in the lying position at the end of the research. No explanation for these low values is at hand other than changes in diet.

RESPIRATION RATE DURING WALKING.

Finally, we have rates obtained immediately prior to, during, and after walking. Inasmuch as the subjects during the walking experiments were confined inside an air-tight metal box, it was impracticable to use the ordinary methods of graphic registration to determine the respiration rate. Recourse was thus had to the special technique outlined on page 130 of this report. Although in a preliminary test it was possible so to adjust the technique for the individual subjects as to obtain most satisfactory records, in the actual experiments we were able to adjust the subject for only a moment, and the experiment was then immediately begun without opportunity for subsequent adjustment. As a result, much to our regret, a considerable number of the records are illegible. This frequently happened with the records of a particular subject, indicating that the difficulty was in the adjustment for that especial man.

The respiration rate is commonly recorded in respirations per minute, and we have followed this custom in presenting the previous data. In the records with the treadmill chamber, however, we were unable to count the number of respirations, as was possible from the graphic records obtained from the pneumograph around the chest in the experiments with the respiratory-valve apparatus, or to record the rise and fall of a spirometer as in the experiments with the portable respiration apparatus. It was necessary to depend here upon short photographic records; consequently the actual number of respiration cycles counted was, at times, rather few and the few records had to be multiplied to bring them to the per minute basis. While the pulse-rate may be advantageously counted for 30 seconds or even as low as 20 seconds, and raised to values per minute without serious error, it is a legitimate question as to whether or not it is possible to count 4, 5, or even less respiratory cycles, determine the length of time photographically to 0.01 part of a second, and then raise this to a rate per

minute on the assumption that the regularity of breathing would be the same throughout the rest of the minute. In lieu of longer records it has been necessary to do this. The results obtained by the photographic method are therefore recorded only to whole numbers in table 110, in which the values are given for the respiration rate with the subject standing before walking and those found 1, 6, 12, 24, and 26 minutes after the walking began. A few records taken at other intervals are given in footnotes. Finally, a few values are recorded

TABLE 110.—*Respiration rate before, during, and after 24 minutes of level walking on a treadmill—Squads A and B.*

Date and subject.	Respiration rate.						
	Standing before walking.	Minutes after walking began.					Standing during first 30 seconds after walking ended.
		1[1]	6	12	24	26	
Squad B.							
Normal diet:							
Jan. 6, 1918.							
Har	....	26	26	22	25	......	....
How	18	24	18	21	25	......	....
Ham	....	......	30	29	26	......	....
Kim	....	20	22	21	23	......	....
Sch	18	......	24	......	25	......	....
Liv	....	31	28	28	31	......	....
Sne	25	22	23	23	......	......	....
Tho	....	23	27	25	......	......	....
Van	....	25	25	23	20	......	....
Wil	....	......	27	26	27	......	....
Reduced diet:							
Jan. 28, 1918.							
Fis	....	22	24	21	20	27	20
How	....	17	20	......	......	22	18
Ham	18	22	27	27	28	24	23
Kim	....	22	17	18	22	23	17
Sch	....	23	25	23	26	......	....
Liv	....	26	25	25	28	......	....
Sne	18	26	29	26	31	26	23
Wil	....	20	23	26	25	......	....
Squad A.							
Reduced diet:							
Feb. 3, 1918.							
Bro	....	26	23	23	23	25	20
Can	....	......	21	19	21	24	20
Kon	....	26	26	26	28	......	20
Gar	....	18	20	21	22	......	17
Gul[2]	16	18	21	22	24	22	20
Moy	14	18	18	15	21	23	13
Pea	20	......	27	28	29	......	18
Pec	17	21	22	......	......	......	20
Tom	14	17	18	19	17	20	17
Vea[3]	18	20	21	23	24	24	17

[1] The respiration rates for January 28 and February 3 were recorded during the first minute.

[2] The respiration rate of *Gul* after he had walked 4 minutes was 21; after 8 minutes, 27; after 14 minutes, 23; after 16 minutes, 22; after 18 minutes, 24; after 20 minutes, 22; after 22 minutes, 23.

[3] The respiration rate of *Vea* after he had walked 2 minutes was 23; after 4 minutes, 22; after 10 minutes, 24; after 14 minutes, 24; after 18 minutes, 24; after 20 minutes, 24; after 22 minutes, 25.

in the last column which were obtained with the subject standing after walking ceased. The actual number of respiratory cycles counted were usually not far from 6 to 9, but occasionally there were no more than 4 and rarely but 2. Special attention will be called to those values lower than 4 in discussing the table, particularly if the count seems in any sense abnormal, for it is obvious that these few respiratory cycles should not be accorded the significance of the longer counts.

The most important point in studying the respiration rate under these conditions is the transition from the standing position to walking. With practically all of these subjects we have the standing respiration rate which was determined in connection with the experiments on the portable respiration apparatus. It seemed best, however, to attempt to obtain the standing respiration rate immediately prior to the beginning of the walking on the treadmill and under the same conditions. Unfortunately, owing to difficulty of instrumental adjustment, but few of these values could be obtained (see first column of table). While from the standpoint of a study of the respiration rate this is of course a serious omission, the exigencies of experimentation demanded that the walking begin immediately. On the other hand, when legible records were obtained, the rates after 1, 6, 12, 24, and 26 minutes show clearly the influence of the continued walking upon the respiratory rhythm.

The respiration in this chamber was not under strictly normal conditions, for after the first minute the percentage of carbon dioxide in the air inside the chamber was perceptibly higher than that of the room air. In the first 2½ minutes that the subject walked on the treadmill the cover of the respiration chamber was not closed down (see p. 132)[1]; hence the respiration rate recorded for the first minute was obtained under normal conditions. The subsequent records, and particularly those for the twenty-fourth minute, were obtained with the subject breathing air in which the percentage of carbon dioxide was gradually increasing; rarely, however, did it exceed 0.9 per cent; the average proportion was not far from 0.6 to 0.7 per cent. The relatively few records obtained after 26 minutes of walking were secured when the subject was still walking upon the treadmill, but the cover of the respiration apparatus had been raised and he was breathing essentially normal, outdoor air.

With these preliminary statements regarding the actual conditions obtaining during the experiment, the data in the table may be analyzed.

The observations were first made for Squad B on January 6, 1918. Such records as were obtained were for the most part unsatisfactory. In the three cases in which standing records were obtained, the effect of walking was, in the case of *How* and *Sch*, to raise the rate from

[1] On January 6 the cover was lowered directly after the subject entered the chamber.

18 to 24 at the end of 1 and 6 minutes, respectively, while with *Sne* the prewalking respiration rate of 25 fell immediately after the beginning of walking to 22 and continued at 23 for the remainder of the test, a condition exactly opposite that reported with *Sch*. While the data are too few for generalization as to the change from the standing position to walking, the successive records obtained during walking are fairly numerous and show that there was no tendency for the respiration rate either to decrease or to increase as the test proceeded, although there were slight variations. On January 6 the respiration rate with the subject standing after walking was not obtained for any of the men.

Squad B was at this time on normal diet; hence the only conclusion that can be drawn is that the respiratory rate of the subjects inside the respiration chamber is practically unaltered by walking during the short period of 24 minutes, and that the carbon-dioxide increment inside the chamber had no measurable effect upon the respiration rate. This is perhaps the most important point to be noted from this particular test and indicates again that this squad is a true control for the subsequent test made with Squad A, as well as the test with Squad B after the men had been put on low diet. Thus it may be fairly assumed that an increment in carbon dioxide may be ruled out as a factor affecting respiration rate—at least the percentage of carbon dioxide with which we deal here.

On January 28 a second series of walking tests was made with Squad B at the Laboratory during which the respiration rate was counted. An examination of the data given in table 110 shows that here again we were particularly unfortunate in not securing a large number of counts before and after walking. Even a larger number of these records were illegible than in the first test and can not be recorded with any degree of accuracy. The 2 subjects with whom prewalking values were obtained showed an increment due to walking. Of particular significance is the apparent increment in the case of *Sne*, who went from 18 counts to 26 during the first minute of walking. After the first minute the rate rose to 29 per minute. The prewalking value of 18 was based upon a count of only three respiratory cycles and is thus somewhat uncertain. Consequently the evidence is by no means clear from these data that under these conditions walking results in an increased respiration rate. With five of our subjects we have records for standing after walking. In all five cases we find a material drop in respiration rate following the last record obtained for the walking. This fall is as much as 7 respirations in the case of *Fis* and with the other men ranges from 1 to 6.

From the beginning to the end of walking there is an increase with *Fis* of 5 respirations; with *Ham* 6; and with *Kim* 1. With all other subjects except *Sne*, the records are incomplete, but the evidence points to a tendency for a slight increase in the respiration rate as the walking

continued. This, coupled with the striking fall previously noted in practically all cases after the walking ceased, may be an actual indication of an effect of low diet upon the respiration rate.

The absence of respiratory studies with Squad A under normal conditions is much to be regretted. Although we obtained a larger number of prewalking records than with Squad B, they are in large part based upon but few respiratory cycles. Thus with *Pea*, *Pec*, and *Tom* the count is based on 3 cycles each. We did obtain, however, a fairly good record in all cases of standing after walking.

In only 5 cases could the immediate transition from standing to walking be considered, but in all these there is an increase, *i. e.*, 4 with *Moy* and *Pec*, 3 with *Tom*, and 2 with *Gul* and *Vea*. Continued walking produced a slight increase with all of the subjects. In general the counts subsequent to the sixth minute were remarkably uniform. There was, therefore, with this squad a tendency for continued walking to produce a slight increase in the respiratory rate. This is in accordance with the general evidence presented by Squad B. That this can hardly be due to the increment in carbon dioxide is, we believe, proved by the experience with Squad B on January 6, prior to reduced diet. It may thus be taken as probable that during walking with low diet there is a slight tendency for the respiratory rate to increase somewhat. After the cessation of walking, and when the subject was still standing upon the treadmill, the respiration counts in practically every instance decreased, and noticeably so, the most striking instance being that of *Moy*, whose respiration rate fell from 23 to 13. In a certain sense this evidence substantiates the other evidence of the experimental data for the increase from standing to walking, since the reverse from walking to standing produced a fall in the respiratory rhythm. The general tendency towards constancy in respiration rate after the first 6 minutes of walking would imply that this transition takes place in the early part of walking and that the slightly faster rate is maintained fairly uniform throughout the rest of the time of walking. The uniformity in respiration rate after walking is very clearly shown by the numerous records obtained for *Gul* and *Vea* whose respiration rates were counted practically every 2 minutes throughout the test, the rate remaining for the most part extraordinarily constant.

MECHANICS OF RESPIRATION.

In addition to the records of the respiration rate obtained in the experiments with the respiratory-valve apparatus, data regarding the total ventilation of the lungs per minute were also secured. From these two a computation could be made of the volume per respiration. Using the respiratory exchange, particularly the carbon-

dioxide output, one can, assuming a dead space, also compute the carbon-dioxide tension in the alveolar air. In addition to these data we determined directly in a large number of cases the alveolar carbon-dioxide tension by a special technique. (See p. 79.) All of these values are recorded, together with certain other respiratory figures, in table 111.

The data for the total ventilation of the lungs per minute are recorded in the first two columns of the table, the first column giving the ventilation as actually observed from readings of the spirometer, and the second, the same data reduced to 0° C. and 760 mm. pressure.

The actual number of observations made of the total ventilation of the lungs prior to the reduction in diet are very few, only *Can* and *Gar* showing more than one value. The data for October 5 or subsequent thereto were obtained after the reduction in diet began. An inspection of the figures in both columns *a* and *b* shows a distinct tendency for the total ventilation of the lungs, both observed and reduced, to decrease somewhat with the length of time, although not necessarily in direct proportion to it. As a matter of fact, for the most part high values were found only in the first three observations, and but occasionally thereafter. In nearly every case after the first two weeks in October, a high ventilation of the lungs was accompanied by a large oxygen consumption. For example, with *Gar*, after a long series of values for ventilation per minute of 4.5 liters or under (see second column), we find on January 10, 14, and 18 three high values of practically 5 liters or over. These were all accompanied by a distinct increase in the oxygen consumption. The total metabolism is thus actually increased and there is an increased ventilation of the lungs to bring away the excess formation of the carbon dioxide. In general, there is a clear tendency for a decrease in the total ventilation of the lungs with a reduction in diet.

VOLUME PER RESPIRATION.

As stated in the preceding section, the respiration rate per minute showed a tendency to decrease; the volume per respiration has therefore an interest. These volumes are recorded in the last column of table 111. Although these volumes show in a number of instances a slight tendency to decrease, they do not on the whole indicate a profound effect of the low diet. Certain cases, particularly *Vea* and *Gul*, show a tendency towards a pronounced reduction in volume per respiration. As a matter of fact, the values for *Gul* range from 634 c.c. on October 1 and 20 to as low as 399 c.c. on January 21, this being by far the widest difference noted with any of the subjects. *Vea* shows a range from 496 c.c. on October 8 to 381 c.c. on November 5.

In general, however, the slight decrease in the respiration rate which was noted as the research progressed, accompanied by a similar

TABLE 111.—*Ventilation of lungs and alveolar CO_2 tension in valve-apparatus experiments; subjects post-absorptive and in lying position—Squad A.*

Subject and date.	Per minute.				(*e*) Respiratory quotient.	(*f*) Alveolar CO_2 tension (determined).	(*g*) Alveolar CO_2 tension (calculated).	Ventilation (observed) per minute per mm. CO_2 tension.[1]		(*j*) Respiration rate per minute.	(*k*) Volume per respiration.[2]
	(*a*) Ventilation of lungs (observed).	(*b*) Ventilation of lungs (reduced).	(*c*) Carbon dioxide.	(*d*) Oxygen.				(*h*) From calculated CO_2 tension ($a \div g$).	(*i*) From determined CO_2 tension ($a \div f$).		
Bro.	*liters.*	*liters.*	*c.c.*	*c.c.*		*mm.Hg.*	*mm.Hg.*	*c.c.*	*c.c.*		*c.c.*
Sept. 29	4.42	3.99	149	215	0.70	....	45.0	98.2	....	11.8	413
Oct. 5	4.89	4.44	176	210	.84	....	44.3	110.4	....	11.6	466
11	4.58	4.16	148	201	.74	....	47.1	97.2	....	13.7	368
16	4.23	3.80	143	190	.75	....	48.5	87.2	....	12.2	380
26	4.27	3.86	142	194	.74	....	49.0	87.1	....	12.8	365
Nov. 8	4.20	3.79	140	187	.75	44.9	47.6	88.2	93.5	12.1	379
15	3.92	3.53	144	187	.77	44.9	52.9	74.2	87.3	11.4	377
21	4.11	3.68	138	184	.75	47.0	49.5	83.0	87.4	12.3	367
Dec. 8	5.01	4.60	140	186	.75	46.6	35.2	142.3	107.5	12.5	443
15	4.25	3.87	137	177	.77	47.8	45.1	94.2	88.9	12.2	384
18	4.03	3.76	138	176	.78	48.2	48.6	82.9	83.6	12.1	368
Jan. 11	4.61	4.19	147	195	.75	47.2	43.5	106.0	97.7	12.9	398
15	3.98	3.57	142	178	.80	45.2	50.5	78.8	88.1	11.5	384
19	4.18	3.75	136	177	.77	45.4	46.9	89.1	92.1	12.2	377
23	3.90	3.48	126	165	.76	48.4	48.2	80.9	80.6	11.8	364
26	4.17	3.78	129	165	.78	48.5	42.3	98.6	86.0	11.6	397
Feb. 1	4.34	4.01	146	184	.79	47.0	46.0	94.3	92.3	12.4	390
Can.											
Sept. 27	6.42	5.83	201	266	.75	....	35.8	179.3	....	13.0	542
Oct. 4	6.03	5.42	212	253	.84	....	38.9	155.0	....	11.3	588
10	5.60	5.10	180	251	.72	....	39.2	142.8	....	13.0	474
25	5.59	4.96	183	240	.76	....	40.1	139.4	....	12.5	487
Nov. 7	5.38	4.98	180	232	.78	45.4	37.5	143.5	118.5	11.1	542
14	5.31	4.83	165	226	.73	45.5	37.4	142.0	116.7	12.0	487
20	5.48	4.96	175	222	.79	44.1	37.3	146.9	124.3	11.6	519
27	5.76	5.30	189	228	.83	46.6	37.8	152.4	123.6	12.0	526
Dec. 7	5.16	4.72	171	225	.76	45.6	39.2	131.6	113.2	11.5	497
14	5.93	5.24	188	227	.83	46.1	37.1	159.8	128.6	12.4	527
Jan. 7	6.18	5.47	204	251	.81	45.9	37.9	163.1	134.6	12.0	558
11	5.87	5.33	185	245	.76	44.1	35.6	164.9	133.1	11.9	548
15	5.46	4.87	180	221	.81	46.3	38.5	141.8	117.9	11.5	524
19	5.40	4.84	169	226	.75	44.6	39.5	136.7	121.1	13.1	453
22	5.31	4.80	172	219	.79	45.5	38.1	139.4	116.7	11.4	511
26	5.64	5.13	178	225	.79	45.1	35.9	157.1	125.1	11.5	543
Feb. 2	5.48	5.03	184	230	.80	....	38.7	141.6	....	11.6	522
Pre.											
Oct. 2	5.86	5.36	166	215	.77	....	43.3	135.3	....	18.7	346
5	6.28	5.72	176	224	.78	....	42.8	146.7	....	20.0	349
11	6.20	5.62	177	227	.78	....	44.1	140.6	....	19.7	345
18	5.84	5.33	164	217	.76	....	45.5	128.3	....	19.5	327
Kon.											
Oct. 27	6.43	5.80	212	265	.79	....	42.9	149.9	....	16.2	433
29	5.64	5.13	204	257	.79	....	42.7	132.1	....	12.2	507
30	6.61	5.84	211	267	.79	....	36.4	181.6	....	12.8	564

[1] Computed following example of Loewy and Zuntz (Berl. klin. Wochenschr., 1916, **53**, p. 828).

[2] Computed to 37° C., saturated, and prevailing barometric pressure.

TABLE 111.—*Ventilation of lungs and alveolar CO_2 tension in valve-apparatus experiments; subjects post-absorptive and in lying position—Squad A*—continued.

Subject and date.	Per minute.							Ventilation (observed) per minute per mm. CO_2 tension.[1]			
	(*a*) Ventilation of lungs (observed).	(*b*) Ventilation of lungs (reduced).	(*c*) Carbon dioxide.	(*d*) Oxygen.	(*e*) Respiratory quotient.	(*f*) Alveolar CO_2 tension (determined).	(*g*) Alveolar CO_2 tension (calculated).	(*h*) From calculated CO_2 tension ($a \div g$).	(*i*) From determined CO_2 tension ($a \div f$).	(*j*) Respiration rate per minute.	(*k*) Volume per respiration.[2]
Kon—cont.	*liters.*	*liters.*	*c.c.*	*c.c.*		*mm.Hg.*	*mm.Hg.*	*c.c.*	*c.c.*		*c.c.*
Nov. 2	5.93	5.44	187	251	.75	....	40.0	148.2	....	14.9	440
4	6.31	5.85	193	246	.78	....	40.6	155.4	....	17.2	406
6	5.40	4.89	176	240	.73	44.5	40.0	135.0	121.3	12.5	474
8	5.43	4.91	177	240	.74	47.8	39.8	136.4	113.6	12.4	478
15	5.91	5.33	184	245	.76	46.0	40.9	144.5	128.5	15.3	424
21	5.00	4.47	160	214	.75	44.7	40.3	124.1	111.9	12.0	458
28	5.35	4.87	165	210	.79	48.1	39.8	134.4	111.2	13.6	432
Dec. 5	5.38	4.85	183	225	.81	48.9	43.6	123.4	110.0	13.4	441
15	6.04	5.52	184	232	.79	47.5	39.4	153.3	127.2	15.7	426
Jan. 12	5.81	5.06	189	242	.78	49.8	43.2	134.5	116.7	14.7	435
15	5.92	5.28	184	239	.77	47.9	41.9	141.3	123.6	15.9	413
18	5.96	5.40	174	235	.74	45.7	38.9	153.2	130.4	15.9	414
22	5.46	4.95	166	207	.80	49.9	41.6	131.3	109.4	15.1	398
26	4.96	4.50	157	201	.78	48.1	41.3	120.1	103.1	12.9	426
31	5.50	5.06	166	203	.82	46.9	41.0	134.1	117.3	15.4	395
Gar.											
Sept. 27	5.85	5.28	213	271	.79	....	40.9	143.0	....	11.1	575
Oct. 4	5.71	5.13	196	244	.80	....	42.5	134.3	....	13.4	469
10	5.43	4.94	181	239	.76	....	40.9	132.8	....	12.7	470
17	5.09	4.66	177	234	.76	....	41.2	123.5	....	11.2	499
23	5.05	4.63	165	221	.75	....	40.4	125.0	....	12.1	459
Nov. 1	5.02	4.52	164	220	.75	....	41.9	119.8	....	12.3	444
7	5.22	4.83	169	219	.78	44.3	39.5	132.2	117.8	12.7	461
14	4.88	4.44	157	211	.75	44.1	41.1	118.7	110.7	12.2	439
20	4.55	4.11	154	209	.74	43.4	42.1	108.1	104.8	10.8	462
28	4.86	4.42	156	211	.74	43.5	39.9	121.8	111.7	11.6	459
Dec. 7	4.69	4.28	151	205	.74	44.3	40.2	116.7	105.9	11.5	452
14	4.99	4.39	170	202	.84	43.8	40.6	122.9	113.9	10.7	514
Jan. 10	6.00	5.44	177	237	.75	44.0	32.0	187.5	136.4	11.3	596
14	5.83	5.38	195	223	.87	45.0	39.6	147.2	129.6	13.5	485
18	5.46	4.95	173	230	.75	42.6	38.8	140.7	128.2	12.8	471
22	4.66	4.23	148	194	.76	43.2	39.5	118.0	107.9	11.2	458
25	5.11	4.59	155	203	.76	42.4	38.6	132.4	120.5	12.7	445
31	4.86	4.47	153	200	.77	44.3	41.4	117.4	109.7	13.0	414
Gul.											
Oct. 1	5.90	5.36	210	249	.84	....	37.8	156.1	....	10.4	634
7	5.72	5.28	192	241	.80	....	36.8	155.4	....	11.0	577
13	5.84	5.24	181	235	.77	....	38.7	150.9	....	13.8	463
20	5.31	4.85	170	228	.75	....	34.0	156.2	....	9.3	634
22	5.11	4.58	168	221	.76	....	38.4	133.2	....	10.5	530
31	5.38	4.99	178	220	.81	....	35.7	150.7	....	10.2	592
Nov. 4	5.71	5.29	181	224	.81	....	38.6	147.9	....	13.6	464
10	5.33	4.84	171	207	.81	41.6	35.7	149.3	128.1	10.4	570
17	5.26	4.75	164	213	.77	44.6	39.6	132.8	117.9	12.9	448

[1]Computed following example of Loewy and Zuntz (Berl. klin. Wochenschr., 1916, **53**, p. 828).
[2]Computed to 37° C., saturated, and prevailing barometric pressure.

TABLE 111.—*Ventilation of lungs and alveolar CO_2 tension in valve-apparatus experiments; subjects post absorptive and in lying position—Squad A*—continued.

Subject and date.	Per minute.				(e) Respiratory quotient.	(f) Alveolar CO_2 tension (determined).	(g) Alveolar CO_2 tension (calculated).	Ventilation (observed) per minute per mm. CO_2 tension.[1]		(j) Respiration rate per minute.	(k) Volume per respiration.[2]
	(a) Ventilation of lungs (observed).	(b) Ventilation of lungs (reduced).	(c) Carbon dioxide.	(d) Oxygen.				(h) From calculated CO_2 tension ($a \div g$).	(i) From determined CO_2 tension ($a \div f$).		
Gul—cont.	*liters.*	*liters.*	*c.c.*	*c.c.*		*mm.Hg.*	*mm.Hg.*	*c.c.*	*c.c.*		*c.c.*
Nov. 23	5.19	4.59	157	198	.79	44.7	39.2	132.4	116.1	12.8	443
27	5.56	5.10	172	208	.83	45.5	39.6	140.4	122.2	13.9	437
Dec. 4	4.97	4.50	159	214	.74	45.9	43.0	115.6	108.3	13.4	410
11	5.44	5.01	179	197	.91	47.5	38.5	141.3	114.5	11.9	505
17	4.82	4.45	160	193	.83	46.8	41.0	117.6	103.0	11.4	461
Jan. 9	5.20	4.68	170	215	.79	46.6	42.7	121.8	111.6	13.6	426
14	6.00	5.53	209	240	.87	48.5	41.8	143.5	123.7	14.2	474
18	5.33	4.83	161	223	.72	44.8	39.7	134.3	119.0	14.0	421
21	4.53	4.23	143	184	.78	43.1	41.9	108.1	105.1	12.8	399
25	5.19	4.66	153	192	.80	45.1	38.5	134.8	115.1	13.4	429
31	5.17	4.75	156	200	.78	43.4	40.6	127.3	119.1	14.3	400
Mon.											
Sept. 29	6.47	5.85	203	273	.74	....	39.1	165.5	....	15.5	460
Oct. 6	6.86	6.20	207	264	.78	....	35.4	193.8	....	14.7	514
12	6.37	5.80	198	260	.76	....	37.4	170.3	....	14.6	482
19	6.45	5.82	194	258	.75	....	38.5	167.5	....	15.9	443
21	5.93	5.46	193	241	.80	....	37.6	157.7	....	12.7	517
Nov. 3	5.19	4.74	154	226	.68	....	36.7	141.4	....	12.4	461
9	4.95	4.47	162	218	.75	43.7	41.5	119.3	113.3	12.1	448
16	6.18	5.54	185	236	.79	44.6	37.2	166.1	138.6	14.5	468
22	6.32	5.62	185	231	.80	43.2	36.0	175.6	146.3	14.5	479
Dec. 3	6.17	5.61	204	222	.92	45.5	37.5	164.5	135.6	12.6	544
10	6.73	6.12	216	244	.89	44.4	36.5	184.4	151.6	13.9	539
16	5.86	5.46	187	210	.89	50.1	37.8	155.0	117.0	13.2	489
Jan. 10	5.81	5.27	169	225	.75	43.7	32.9	176.6	133.0	12.1	540
14	5.89	5.43	191	217	.88	43.3	36.1	163.2	136.0	12.0	551
17	5.19	4.71	164	217	.76	47.8	37.9	136.9	108.6	11.8	487
21	6.52	6.06	195	231	.84	49.0	34.9	186.8	133.1	14.8	495
25	5.13	4.62	159	212	.75	46.9	38.0	135.0	109.4	12.1	471
30	6.07	5.63	182	225	.81	45.4	36.2	167.7	133.7	14.4	469
Moy.											
Oct. 1	4.84	4.39	178	209	.85	....	46.5	104.1	....	12.2	443
7	5.35	4.95	177	232	.76	....	41.1	130.2	....	13.3	447
13	5.14	4.61	170	224	.76	....	42.2	121.8	....	12.5	450
20	5.01	4.57	172	224	.77	....	41.1	121.9	....	11.4	488
Nov. 10	5.08	4.62	161	209	.77	44.8	40.1	126.7	113.4	12.8	443
17	4.78	4.31	149	202	.74	45.7	40.2	118.7	104.6	12.0	438
23	4.52	3.99	146	194	.75	46.2	43.5	103.9	97.8	11.8	419
Dec. 4	4.55	4.12	154	202	.76	46.4	42.3	107.6	98.1	11.0	456
11	4.54	4.16	157	188	.83	47.6	43.2	105.1	95.4	11.1	450
17	4.75	4.37	158	196	.81	48.3	42.3	112.3	98.3	11.7	441
Jan. 9	5.32	4.79	177	229	.77	46.4	39.7	134.0	114.7	12.0	493
17	4.94	4.49	162	218	.74	47.2	39.9	123.8	104.7	11.6	472
20	4.58	4.21	153	194	.79	47.1	41.1	111.4	97.2	11.2	456
24	4.84	4.35	154	198	.78	46.2	40.2	120.4	104.8	11.8	451
30	4.60	4.26	154	191	.81	47.3	39.9	115.3	97.3	10.6	482

[1]Computed following example of Loewy and Zuntz (Berl. klin. Wochenschr., 1916, **53**, p. 828).
[2]Computed to 37° C., saturated, and prevailing barometric pressure.

TABLE 111.—*Ventilation of lungs and alveolar CO_2 tension in valve-apparatus experiments; subjects post absorptive and in lying position—Squad A*—continued.

Subject and date.	Per minute. (a) Ventilation of lungs (observed).	Per minute. (b) Ventilation of lungs (reduced).	Per minute. (c) Carbon dioxide.	Per minute. (d) Oxygen.	(e) Respiratory quotient.	(f) Alveolar CO_2 tension (determined).	(g) Alveolar CO_2 tension (calculated).	Ventilation (observed) per minute per mm. CO_2 tension.[1] (h) From calculated CO_2 tension ($a \div g$).	Ventilation (observed) per minute per mm. CO_2 tension.[1] (i) From determined CO_2 tension ($a \div f$).	(j) Respiration rate per minute.	(k) Volume per respiration.[2]
Pea.	*liters.*	*liters.*	*c.c.*	*c.c.*		*mm.Hg.*	*mm.Hg.*	*c.c.*	*c.c.*		*c.c.*
Sept. 29	6.31	5.70	204	253	.81	....	49.6	127.2	....	19.9	349
Oct. 6	5.67	5.12	194	243	.80	....	47.7	118.9	....	16.0	390
12	5.98	5.44	186	238	.78	....	41.2	145.1	....	15.9	414
19	5.41	4.88	172	216	.80	....	44.8	120.8	....	15.3	386
Nov. 3	4.84	4.43	161	201	.80	....	46.8	103.4	....	14.1	379
9	5.25	4.75	163	204	.80	45.6	44.0	119.3	115.1	15.1	381
16	4.70	4.20	158	194	.81	39.9	47.0	100.0	117.8	13.1	392
22	5.01	4.46	154	192	.80	41.9	44.2	113.4	119.6	14.5	380
Dec 3	5.26	4.81	179	209	.86	49.2	45.4	116.5	107.5	14.5	405
10	5.42	4.90	193	205	.93	47.0	45.0	120.4	115.3	13.4	449
13	4.91	4.46	165	195	.85	46.1	47.2	104.0	106.5	13.9	384
16	4.63	4.32	159	197	.81	48.0	46.4	99.8	96.5	13.0	393
Jan. 8	4.68	4.19	166	209	.79	49.9	49.4	94.7	93.8	13.3	392
12	5.19	4.54	162	214	.76	44.7	42.7	121.5	116.1	13.8	412
17	4.63	4.20	153	201	.76	47.6	47.4	97.7	97.3	13.7	374
20	4.81	4.45	149	190	.78	47.3	43.1	111.6	101.7	14.1	382
24	4.51	4.05	141	187	.75	45.0	48.6	92.8	100.2	14.3	346
30	4.33	4.01	143	183	.78	45.5	49.4	87.7	95.2	13.8	349
Feb. 1	4.69	4.33	147	185	.79	46.5	45.6	102.8	100.9	14.4	363
Pec.											
Oct. 3	5.20	4.75	173	219	.79	....	42.7	121.8	....	13.2	434
9	5.48	5.03	168	223	.75	....	40.8	134.3	....	14.9	407
18	5.26	4.81	165	216	.76	....	40.6	129.6	....	13.4	430
24	5.27	4.79	165	206	.80	....	40.7	129.5	....	13.6	426
29	5.99	5.45	204	242	.84	....	40.4	148.3	....	13.1	502
Nov. 2	4.85	4.45	153	197	.78	....	39.6	122.5	....	12.0	446
6	4.66	4.22	140	188	.74	47.0	39.4	118.3	99.1	12.1	422
13	4.64	4.27	144	188	.77	....	40.5	114.6	....	12.2	420
19	4.33	3.99	139	183	.76	40.2	42.9	100.9	107.7	12.0	403
26	5.13	4.71	182	208	.88	47.2	43.7	117.4	108.7	12.3	461
Dec. 6	4.56	4.15	146	180	.81	43.7	40.4	112.9	104.3	11.3	445
12	4.60	4.23	146	180	.81	45.7	40.2	114.4	100.7	11.4	442
19	4.56	4.20	146	182	.80	44.6	40.6	112.3	102.2	11.4	439
Jan. 7	4.94	4.38	147	203	.72	44.6	39.3	125.7	110.8	12.4	432
16	4.78	4.37	139	186	.75	......	38.2	125.1	....	12.9	416
21	4.64	4.32	138	176	.78	42.8	36.9	125.7	108.4	11.8	442
24	4.70	4.22	140	177	.79	44.2	39.4	119.3	106.3	12.2	423
29	4.62	4.15	138	170	.81	43.2	40.3	114.6	106.9	12.3	410
Feb. 2	4.91	4.52	147	185	.79	....	38.1	128.9	....	12.5	434
Spe.											
Oct. 2	4.98	4.56	182	231	.79	....	42.2	118.0	....	10.5	524
8	5.49	5.02	185	241	.77	....	40.3	136.2	....	12.4	490
17	5.16	4.72	181	220	.82	....	40.5	127.4	....	10.8	525
23	4.55	4.17	149	201	.74	....	39.3	115.8	....	10.3	485
30	5.29	4.67	171	213	.80	....	37.6	140.7	....	10.7	539

[1]Computed following example of Loewy and Zuntz (Berl. klin. Wochenschr. **1916**, 53, p. 828).
[2]Computed to 37° C., saturated, and prevailing barometric pressure.

TABLE 111.—*Ventilation of lungs and alveolar CO_2 tension in valve-apparatus experiments; subjects post absorptive and in lying position—Squad A*—continued.

Subject and date.	Per minute. (a) Ventilation of lungs (observed).	Per minute. (b) Ventilation of lungs (reduced).	Per minute. (c) Carbon dioxide.	Per minute. (d) Oxygen.	(e) Respiratory quotient.	(f) Alveolar CO_2 tension (determined).	(g) Alveolar CO_2 tension (calculated).	Ventilation (observed) per minute per mm. CO_2 tension.[1] (h) From calculated CO_2 tension ($a \div g$).	Ventilation (observed) per minute per mm. CO_2 tension.[1] (i) From determined CO_2 tension ($a \div f$).	(j) Respiration rate per minute.	(k) Volume per respiration.[2]
Spe— cont.	*liters.*	*liters.*	*c.c.*	*c.c.*		*mm.Hg.*	*mm.Hg.*	*c.c.*	*c.c.*		*c.c.*
Nov. 1	4.99	4.49	163	208	.78	....	39.9	125.1	....	11.2	484
5	5.21	4.81	166	208	.80	35.1	39.2	132.9	148.4	12.5	459
12	5.10	4.55	173	198	.87	44.8	39.6	128.8	113.8	10.4	534
18	4.84	4.36	150	193	.78	41.2	37.5	129.1	117.5	10.9	487
24	4.54	4.06	146	186	.78	40.4	39.6	114.6	112.4	10.6	473
Dec. 8	4.21	3.86	142	187	.76	43.4	40.9	102.9	97.0	9.8	474
Tom.											
Oct. 3	5.19	4.74	170	204	.83	....	43.9	118.2	....	14.1	405
9	5.34	4.91	172	224	.77	....	39.9	133.8	....	13.1	453
16	5.45	4.88	159	204	.78	....	38.9	140.1	....	14.2	419
22	5.28	4.73	162	205	.79	....	41.2	128.2	....	13.8	416
31	4.79	4.44	146	191	.76	....	39.2	122.2	....	12.8	420
Nov. 13	4.28	3.94	141	173	.82	50.5	42.9	99.8	84.8	11.3	419
19	4.25	3.91	136	177	.77	46.7	42.9	99.1	91.0	11.8	402
26	5.17	4.75	176	182	.97	47.9	40.3	128.3	107.9	11.6	493
Dec. 6	4.26	3.89	136	181	.76	48.7	43.6	97.7	87.5	11.9	397
13	4.61	4.18	143	187	.76	49.3	42.4	108.7	93.5	12.5	400
19	4.41	4.05	128	169	.76	46.5	41.5	106.3	94.8	13.0	372
Jan. 12	5.02	4.39	159	198	.80	50.6	42.7	117.6	99.2	13.1	420
16	4.68	4.28	143	194	.74	47.6	41.3	113.3	98.3	13.2	398
20	4.32	3.96	135	180	.75	49.9	43.2	100.0	86.6	12.4	388
23	4.67	4.17	137	172	.80	47.1	41.5	112.5	99.2	13.3	387
29	4.23	3.79	135	170	.79	48.9	45.7	92.6	86.5	12.1	381
Vea.											
Oct. 2	5.29	4.85	178	227	.78	....	40.4	130.9	....	12.2	480
8	4.76	4.35	161	219	.74	....	40.1	118.7	....	10.6	496
15	5.48	4.90	168	217	.78	....	40.1	136.7	....	13.8	432
21	4.39	4.04	151	210	.72	....	44.8	98.0	....	11.6	419
27	4.93	4.45	152	206	.74	....	42.1	117.1	....	13.4	402
Nov. 5	5.02	4.63	157	215	.73	31.9	43.7	114.9	157.4	14.5	381
12	5.44	4.86	179	214	.84	45.9	42.8	127.1	118.5	13.6	436
18	4.31	3.88	146	191	.77	47.7	43.6	98.9	90.4	10.8	438
24	4.37	3.90	142	179	.79	44.9	41.4	105.6	97.3	10.7	450
Dec. 5	4.63	4.17	151	191	.79	47.8	43.1	107.4	96.9	12.1	420
12	4.22	3.88	149	186	.80	49.4	47.4	89.0	85.4	11.4	405
18	4.48	4.18	145	186	.78	48.7	42.8	104.7	92.0	12.2	406
Jan. 8	4.82	4.30	158	200	.79	48.5	44.2	109.0	99.4	13.0	412
11	5.24	4.76	162	200	.81	44.7	39.0	134.4	117.2	13.1	445
16	4.88	4.45	149	190	.78	46.4	39.2	124.5	105.2	12.7	431
19	4.49	4.04	147	188	.78	45.9	40.4	111.1	97.8	10.6	467
23	4.63	4.13	144	188	.77	45.4	41.2	112.4	102.0	12.1	421
29	4.43	3.97	151	180	.84	47.2	41.7	106.2	93.9	10.0	483
Feb. 1	4.49	4.13	145	178	.81	46.8	42.9	104.7	95.9	12.2	408

[1]Computed following example of Loewy and Zuntz (Berl. klin. Wochenschr., 1916, **53**, p. 828).
[2]Computed to 37° C., saturated, and prevailing barometric pressure.

decrease in total ventilation of the lungs, results in an approximately constant volume per respiration but the data are so irregular that it is difficult to discover any particular influence of the low diet upon the volume per respiration, and one must infer that this remains practically unchanged.

TIME RELATIONS OF MAXIMUM AND MINIMUM RESPIRATION VOLUMES.

To indicate if there is any regularity in the incidence of the maximum volume per respiration and the time of the experiment and for similar indications as to the appearance of the minimum, we present in table 112 the maximum, minimum, and average values for the volume per respiration of Squad A. The average volumes per respiration ranged from 520 c.c. with *Can* to 342 c.c. with *Fre*. (See footnote 2 of table 112.) These two men likewise represent the extremes in body-weight, *Can* having a body-weight of 79.75 kg. and *Fre* a body-weight of 57.50 kg.

TABLE 112.—*Maximum, minimum, and average volume per respiration determined in experiments with respiratory valve apparatus*[1]—*Squad A, subjects post-absorptive and in lying position.*

Subject.[2]	Date.	Volume per respiration.[3]	Subject.	Date.	Volume per respiration.[3]
Bro:		c.c.	*Moy:*		c.c.
Maximum...	Oct. 5, 1917.....	466	Maximum..	Jan. 9, 1918.....	493
Minimum...	Jan. 23, 1918.....	364	Minimum...	Nov. 23, 1917.....	419
Average....	....	389	Average....	....	455
Can:			*Pea:*		
Maximum...	Oct. 4, 1917.....	588	Maximum..	Dec. 10, 1917.....	449
Minimum...	Jan. 19, 1918.....	453	Minimum...	Jan. 24, 1918.....	346
Average.....	....	520	Average....	....	385
Kon:			*Pec:*		
Maximum...	Oct. 30, 1917.....	564	Maximum..	Oct. 29, 1917.....	502
Minimum...	Jan. 31, 1918.....	395	Minimum...	Nov. 19, 1917.....	403
Average....	....	442	Average....	....	433
Gar:			*Spe:*		
Maximum...	Jan. 10, 1918.....	596	Maximum..	Oct. 30, 1917.....	539
Minimum...	Jan. 31, 1918.....	414	Minimum..	Nov. 5, 1917.....	459
Average.....	....	476	Average....	....	498
Gul:			*Tom:*		
Maximum...	Oct. 1 and 20, 1917.	634	Maximum..	Nov. 26, 1917.....	493
Minimum...	Jan. 21, 1918.....	399	Minimum...	Dec. 19, 1917.....	372
Average....	....	486	Average....	....	411
Mon:			*Vea:*		
Maximum...	Jan. 14, 1918.....	551	Maximum..	Oct. 8, 1917.....	496
Minimum...	Oct. 19, 1917.....	443	Minimum...	Nov. 5, 1917.....	381
Average....	....	492	Average....	....	433

[1] See table 111.

[2] Values for *Fre* are as follows: Maximum, Oct. 5, 349 c.c.; minimum, Oct. 11, 327 c.c.; average, 342 c.c.

[3] Computed to 37° C., saturated, and prevailing barometric pressure.

An examination of the relationship between the progress of the experiment and the maximum volume does not show any uniformity. While, with a certain number, the maximum volume is to be found at the beginning of the experiment, with three of the men it is noted as late as January 9 or thereafter. Similarly the appearance of the minimum is not uniformly noted. Aside from the value for *Fre*, which is liable to misconception, owing to the shortness of the time in which he was studied, we still have a minimum value appearing with *Mon* as early as October 19. With *Bro*, *Can*, *Kon*, *Gar*, *Gul*, and *Pea* the minimum occurs during the last half of January.

These measurements, it will be recalled, all refer to the total volume per respiration and were usually averaged from 100 or more respirations. Hence the actual maximum and minimum figures are of significance. The highest volume per respiration, 634 c.c., was noted with *Gul* on October 1 and 20. The absolute minimum, 346 c.c., was noted with *Pea* on January 24, 1918. Undue stress should not be laid upon either the minimum or maximum results, for obviously their significance is chiefly in the relationship to the respiration rate existing at the time. In general the volume per respiration of these subjects appears to be well within normal limits, with perhaps a slight tendency towards low rather than high values, when compared with normal subjects of similar age previously studied in this Laboratory.

ALVEOLAR CARBON DIOXIDE.

The physiological significance of the alveolar carbon dioxide has been emphasized in practically all studies of the respiration in recent years. The delicacy of the regulation of the mechanism for respiration and the important rôle played by alveolar carbon dioxide are becoming increasingly evident. Although in the earlier stages of the investigation sufficient data were secured in the respiratory studies to compute the alveolar carbon dioxide by assuming a constant dead space, we deemed it important to make direct studies of this factor. Unfortunately these studies were not begun until about the middle of November. Thereafter direct alveolar carbon-dioxide determinations were carried out by the method outlined on page 79 in connection with each experiment with the respiratory-valve apparatus. The technique used gives results[1] comparable to those obtained by the Plesch-Higgins[2] method, and consequently the values approach the carbon-dioxide tension of the venous blood rather than that of the arterial blood. These values are recorded in column *g* of table 111. In almost every instance they represent the average results of two well-agreeing determinations obtained immediately after the respiratory-exchange experiments, the subjects being always under uniform condi-

[1] Roth, Boston Med. and Surg. Journ., 1918, **179**, p. 130.
[2] Higgins, Carnegie Inst. Wash. Pub. 203, 1915, p. 171.

tions. While the agreement of these values with a large number of the subjects is perhaps all that could be expected, certain instances, such as the variation with *Mon* of 43.2 to 50.1 mm., is rather wider than one would normally expect, likewise that with *Gul* from 41.6 to 48.5 mm., with *Pea* from 39.9 to 49.9 mm., with *Pec* from 40.2 to 47.2 mm., with *Spe* from 35.1 to 44.8 mm., and with *Vea* from 31.9 to 49.4 mm. On the whole the values lie considerably above 43 mm., which is about that ordinarily found with normal individuals. It seems important, also, to find if the variations from day to day were inherent in the method or were actually existing with all subjects. Fortunately for this purpose we have comparable values for comparison which were calculated from the respiratory exchange as determined by the respiratory-valve apparatus.

This computation was carried out in the usual way by using the ventilation of the lungs and the carbon-dioxide production according to the following formula:

$$\underset{\text{(per cent)}}{\text{Alveolar carbon dioxide}} = \frac{\text{Carbon dioxide excreted per minute}}{\text{Total ventilation} - (\text{Respiration rate} \times 140 \text{ c.c. dead space}).}$$

$$\text{Per cent } CO_2 \times \text{barometric pressure} - 47 \text{ mm.} = \text{tension in millimeters.}$$

This method of computing the alveolar carbon dioxide involved the use of a constant dead space in the respiratory passages of 140 c. c., in accordance with the method used by Loewy and Zuntz.[1]

The irregularities noted from day to day with *Pea* seem to be verified in large part by the computed values, although certain exceptions appear contrary to this. Thus the low value of 39.9 mm. found by the direct method on November 16 is not accompanied by a low value computed by the indirect method. It should be borne in mind that the computation method assumes a constant dead space for all the subjects. This might introduce an error in comparisons of values for different subjects, but it is hardly probable that the dead space would change so profoundly from day to day as to effect a real variation in the calculated alveolar carbon dioxide. Therefore the comparison of the variations in the two sets of values is based on sound principles. Although we had the cooperation of the subjects and the long period of observation made them thoroughly familiar with the technique, the fact that somewhat more regular values for the alveolar carbon-dioxide tension are found by the computation method than those secured by direct determination should not be lost sight of, and this leads one to believe that the calculated values in the long run probably have a higher degree of accuracy and their variations from day

[1] Loewy and Zuntz, Berl. klin. Wochenschr., 1916, **53**, p. 828.

to day are more to be relied upon than are those directly determined. Consequently we may compare, with an even greater degree of confidence, the relationship between the calculated values for the alveolar carbon dioxide at the beginning and end of the long period of undernutrition to see what effect the undernutrition had upon the alveolar carbon dioxide.

Comparing the one or at most two observations before the diet with the average of the last 3 days of the low diet, we find that with *Bro*, *Can*, *Gar*, and *Pea* there was practically no change, with *Gul* a slight tendency for an increase at the end, and with *Mon* and *Moy* a slight decrease. With *Pec* there was a distinct falling off in the alveolar carbon dioxide, with *Tom* no material change, and with *Vea* possibly a slight increase. From a comparison made on this basis, it is difficult to note any particular alteration in the alveolar carbon dioxide due to the altered dietetic conditions, there being no decided tendency, on the average, for the alveolar carbon-dioxide tension to change even after extensive dietetic alterations.

ALVEOLAR CARBON DIOXIDE AND IRRITABILITY OF RESPIRATORY CENTER.

As Loewy and Zuntz[1] point out, unusual significance attaches to the alveolar carbon dioxide since the reaction of the respiratory center to the alveolar carbon dioxide may be taken more or less as an indication of the irritability of the organism. It has been their custom in many of their respiration experiments to compute the relationship between the alveolar carbon dioxide and total ventilation of the lungs, *i. e.*, to express in cubic centimeters per minute the amount of ventilation, not reduced, per millimeter of carbon-dioxide tension in the lungs, and such determinations were made in their experiment on war diet.

Similar computations for our experiment seemed desirable. These have been made on two bases: first, from the alveolar carbon dioxide as actually determined, and second, that found by calculation. The ventilation per minute was obtained by dividing the observed ventilation (see column *a*) by the tension of carbon dioxide, either determined or computed. The results are recorded in cubic centimeters per minute per millimeter of carbon-dioxide tension in columns *h* and *i*, the first being computed from the calculated carbon-dioxide tension and the second from the direct determinations. Bearing in mind the facts that no pronounced tendency was found for the alveolar carbon dioxide to change during the experiment and that in general there was a distinct tendency for the total ventilation of the lungs to become lower as the experiment progressed, one is prepared to find that the ventilation per minute per millimeter of carbon-dioxide tension has a definite tendency to decrease as time goes on.

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[1] Loewy and Zuntz, Berl. klin. Wochenschr., 1916, **53**, p. 825.

Examining first the values drawn from the calculated carbon-dioxide tension (column *h*), we find with *Bro* a decided fall of approximately 20 c.c. per minute, with *Can, Gar*, and *Gul* a decrease, while with subject *Mon* there was a tendency for this value to remain constant. With *Moy* there was an increase from 104 c.c. to an average not far from 116 c.c. With *Pea, Tom*, and *Vea*, on the contrary, there was the usual fall, and with *Pec* practically constant values. In general, the values based upon the calculated alveolar carbon dioxide show a clear tendency to a somewhat less ventilation of the lungs per millimeter of carbon-dioxide tension.

In comparing the calculations based upon the direct determinations of alveolar carbon dioxide, which, unfortunately, were not obtained until after the middle of November, we find that no pronounced or regular change in the ventilation per millimeter is apparent with *Bro, Can, Kon, Gar, Gul, Mon, Pec*, or *Tom*. (See column *i*.) On the other hand, *Moy's* values show a tendency to fall, although high values are found in the early part of January. The values for *Pea* tend to decrease, as do those obtained in one month's observations with *Spe*. The general picture with *Vea* is similar, although high values are again found in the early part of January and the results with him on the whole are irregular.

One must conclude, therefore, that the tendency shown by both sets of figures is, in certain cases, for the ventilation per minute per millimeter of alveolar carbon-dioxide tension to be somewhat lower at the end of the period of reduced diet than at the beginning. In other words, the respiratory center is somewhat less sensitive at the end than before the reduction in diet began, this decrease in sensitivity being due to the low diet. This is in contrast to the results reported by Loewy and Zuntz.[1] No change was found with Loewy, and although variations with Zuntz had been found from time to time during a series of years, as a matter of fact the ventilation per millimeter of alveolar carbon dioxide in the experiment with the war diet was exactly that found with him 28 years before. Their general conclusion is that the low diet did not increase the sensitivity of the respiratory center.

Dr. T. M. Carpenter calls our attention to the fact that with a decrease in respiration rate as shown in a previous section there would be a decrease in the total ventilation, because the personal dead space of the subject would not have to be swept out so many times with a slower respiration rate. This, together with the fact that there was less carbon dioxide to be eliminated, naturally resulted in a lower total ventilation, so that with a fairly constant level of carbon-dioxide tension there would result mathematically a lower volume of expired

[1] Loewy and Zuntz, Berl. klin. Wochenschr., 1916, **53**, p. 825.

air per millimeter of carbon-dioxide tension. To say that this means a change in irritability of the respiratory center would seem to imply that if there is a change in any of the factors of respiration, such as respiration rate, dead space, carbon-dioxide elimination, and total ventilation, the irritability would be also changed. So that when we say that the irritability of the respiratory center is decreased with these subjects, it is only in the sense that Loewy and Zuntz use the term.

The general conclusions from the study of the mechanics of respiration and particularly the alveolar air for the subjects in our research are that the low diet produces a distinctly lower respiratory activity, and although the alveolar carbon dioxide remains essentially constant, there is a definite tendency toward a lessened work of ventilation, with a decreased sensitivity of the respiratory center. The correlation of this finding with the total metabolism must be noted in subsequent discussion. The general lowering of the metabolism shown calls for a lower ventilation of the lungs for the removal of carbon dioxide and hence the work of ventilation is less.

Subsidiary evidence regarding the reasonable constancy in the alveolar carbon dioxide is supplied by the fact that the alveolar carbon dioxide with *Pea* was directly determined before a cross-country run on November 28 and found to be 48.4 mm.; immediately after the cross-country run, which was 6¾ miles (10.9 km.), it was found to be 42.9 mm. The respiration rate under these conditions was, as found from kymograph records, 18.3 respirations per minute prior to the run and 23.3 respirations subsequent to the run, although it was impossible to adjust the apparatus and get a record until some little time had elapsed after the completion of the run.

GASEOUS METABOLISM DURING REST. (INDIRECT CALORIMETRY.)

Although the body-weight over considerable periods of time may properly be taken as an index of nutritional level, or at least of variations in nutritional level, it of itself gives no idea as to the exact caloric requirements. It seemed imperative, therefore, to measure quantitatively the caloric output of these men at the different nutritional or different weight-levels. The ideal apparatus for measuring the caloric output is the respiration calorimeter, but its use was precluded, first, on account of the impossibility of transporting this complicated apparatus to Springfield, and second, because of the length of time required for the several experiments. Consequently the determination of the gaseous exchange as frequently as possible throughout the entire period of dietetic control seemed to be the best method for obtaining information regarding the caloric requirements.

As stated in the chapter on technique (see p. 82), the gaseous metabolism of nine of the men was determined nearly every morning

in Springfield, these measurements including observations of the oxygen consumption and in many cases of the carbon-dioxide production. In addition, the carbon-dioxide output of the squad as a group was measured biweekly during sleep in a large respiration chamber in Boston. Since in the Springfield measurements, the subjects were always in the post-absorptive condition—that is, without food for at least 12 hours—we have clear records of the basal metabolism. The experiments made in Boston during the night were not strictly basal in that they did not conform to the fullest demand for the post-absorptive condition, since the experiment began less than 12 hours after the preceding meal. On the other hand, the measurements were made for the most part during deep sleep and after a very light supper and in all probability they represent the basal demand.

It was extremely important to determine the basal metabolism prior to the dietetic restriction and thus establish the normality of these men and find whether the variations in metabolism were within the so-called normal limits. As has been frequently pointed out in this monograph, the period for the measurement of basal values during normal diet was too short with all factors studied in this research. Since there was a possibility that it might be necessary to conclude the observations at Christmas, we were obliged to choose between sacrificing the total length of the experiment by prolonging the period of normal diet, or shortening this period so as to obtain extended measurements with restricted diet. The second alternative seemed to us the more desirable; consequently, the values during normal diet for these men were determined on a relatively few days in the latter part of September and during the first few days of October.

BASAL METABOLISM PRIOR TO DIET RESTRICTION.

The basal metabolism was measured individually in Springfield by two forms of respiration apparatus: First, a respiratory-valve apparatus employing a mask, Tissot valves, and a carefully calibrated spirometer, with Haldane gas-analysis apparatus for the analysis of the expired air (a combination highly recommended by Dr. T. M. Carpenter); and second, a portable respiration apparatus of new design. These measurements were made only with the men in Squad A and with *Ham*, one of the men in Squad B. Finally, the metabolism measurements in the group respiration chamber in Boston were also practically basal. These group measurements were made with both Squads A and B.

The values obtained with the respiratory-valve apparatus are of the greater significance, particularly for the normal period, for several reasons. In the first place, the apparatus had long been in use and thus was thoroughly tested. The technique had also been carefully developed. The portable respiration apparatus, while thoroughly

tested on specially trained subjects, had never been used to any extent on untrained subjects. Hence, during the first few days of the experiment, the portable respiration apparatus was practically an untried instrument, and the data obtained with it can not have the scientific value of those obtained on the respiratory-valve apparatus. Our discussion of the results, therefore, especially of the basal metabolism prior to diet restriction, must deal more particularly with the values found with the respiratory-valve apparatus. In most instances, however, the values for oxygen consumption secured with the portable respiration apparatus have been averaged with the other results. After the first few days the results with both forms of apparatus are considered of equal value.

The chief responsibility for the experimental work with the portable respiration apparatus at Springfield devolved upon Mr. Louis E. Emmes, whose experience with the apparatus led to the betterment of the technique. Mr. Edward L. Fox likewise made a large number of the respiration experiments with this apparatus.

INDIVIDUAL MEASUREMENTS OF BASAL METABOLISM, SQUAD A.

The data regarding the normal basal metabolism of Squad A have been recorded in table 113, which gives the body-weight without clothing, height, body-surface as calculated from the height-weight chart, average oxygen consumption per minute, respiratory quotient, and the heat computed from the gaseous metabolism on several bases—*i. e.*, per hour, per 24 hours, per kilogram per 24 hours, and per square meter per 24 hours—and finally, the predicted heat from a series of equations recently published by the Carnegie Institution of Washington.[1] The differences, absolute as well as percentile, between the values computed per 24 hours and those predicted are given in the last columns of the table. This table gives results obtained for all the men in Squad A, including *Fre*, *Spe*, and *Kon;* the three last were members of the squad for only a part of the experiment. Additional data are included for one member of Squad B (*Ham*), whose basal metabolism was determined on several occasions prior to the period of diet restriction in some tests of the apparatus.

An examination of the figures in this table reveals nothing unusual. The average respiratory quotient for Squad A (excluding *Bro*) is 0.80. The average values for the heat, computed on the various bases are per kilogram per 24 hours, 25.5 calories, and per square meter per 24 hours, 949 calories. The normality of these figures on the whole is indicated by the fact that the average respiratory quotient of 89 men as reported from this Laboratory[2] was 0.83 as against 0.80 found in the normal

[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919.
[2] Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 139.

TABLE 113.—*Normal basal metabolism of Squad A, prior to reduction in diet.*

Subject.	Body-weight without clothing.	Height.	Body-surface by height-weight chart.	(a) Average O_2 per minute.	(b) Respiratory quotient.	Heat (computed). (c) Per hour.	(d) Per 24 hours.	(e) Per kg. per 24 hours.	(f) Per sq. m. (height-weight chart) per 24 hours.	(g) Heat per 24 hours predicted by Harris and Benedict.	Difference found greater (+) or less (−) than Harris and Benedict predictions. (h) Amount (g−d).	(i) Per cent (100h÷g).
	kg.	*cm.*	*sq. m.*	*c.c.*		*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	
Bro..........	61.8	167	1.70	212	0.70[1]	61.7	1481	24.0	871	1576	− 95	− 6.0
Can..........	79.8	177	1.97	255	.80	73.3	1758	22.0	893	1874	−116	− 6.2
Fre..........	57.5	167	1.64	231	.77	66.2	1589	27.6	969	1524	+ 65	+ 4.3
Kon..........	69.0	168	1.78	264	.79	75.8	1818	26.4	1021	1721	+ 97	+ 5.6
Gar..........	71.3	171	1.83	263	.80	75.6	1815	25.5	992	1754	+ 61	+ 3.5
Gul..........	66.8	166	1.75	244	.84	70.8	1698	25.4	974	1653	+ 45	+ 2.7
Mon..........	68.8	171	1.81	273	.74	77.4	1858	27.0	1027	1652	+206	+12.5
Moy..........	63.5	174	1.77	235	.85	68.3	1638	25.8	926	1655	− 17	− 1.0
Pea..........	69.3	169	1.79	255	.81	73.6	1766	25.5	987	1723	+ 43	+ 2.5
Pec..........	64.3	170	1.75	230	.79	66.2	1589	24.7	908	1504	+ 85	+ 5.7
Spe..........	63.5	171	1.75	252	.79	72.2	1733	27.3	990	1667	+ 66	+ 4.0
Tom..........	59.5	176	1.73	219	.83	63.6	1526	25.6	882	1596	− 70	− 4.4
Vea..........	65.8	175	1.80	234	.78	66.8	1604	24.4	891	1698	− 94	− 5.5
Ham (Squad B)	73.8	184	1.96	270	.82	78.2	1877	25.4	958	1867	+ 10	+ 0.5

[1] In computing the heat values for this subject, the respiratory quotient for October 5 (0.84) was used.

measurements of Squad A. Recently Dr. T. M. Carpenter, Mr. L. E. Emmes, and Miss M. F. Hendry, of the Nutrition Laboratory staff, have measured the metabolism of 17 Harvard Medical School students,[1] who showed an average respiratory quotient of 0.82. The heat production per hour per square meter of body-surface found with these 17 men was, on the average, 38.3 calories, a value about 3 per cent less than that found by us with the members of Squad A, *i. e.*, 39.5 calories. A possible explanation of the slightly higher values obtained in our measurements is the fact that our subjects included a relatively large number of men in excellent physical training, and it has previously been shown that athletes have a perceptibly higher basal metabolism than is found with normal non-athletic individuals.[2]

A comparison between the values found for total heat production per 24 hours and those predicted by the new equations is of special interest. Paying particular attention to the differences, which are shown in the next to the last column of the table, we find that 8 out of the 13 men of Squad A show plus values, that is, have a somewhat higher metabolism than that predicted. The most striking variation from the predicted value is that of *Mon*, whose total heat production as measured per 24 hours was 1,858 calories as compared with a predicted value of 1,652 calories. A more careful consideration of this case seems desirable. It should be stated, however, at the outset that the value of 1,858 calories was based upon measurements made on one day only, although in two well-agreeing periods with the respiratory-valve apparatus. Until recently the experimenters in the Nutrition Laboratory have been inclined to consider the element of novelty a rather important one, inasmuch as the results obtained in the first experiment with a subject were liable, we believed, to be somewhat higher than normal. The recent experiments with Harvard Medical School students have completely disproved this contention, however, and a carefully conducted respiratory exchange experiment, with due allowance for a period of quiet prior to the actual gaseous metabolism test, should give values that are trustworthy. In every instance the subject should be lying down in complete muscular repose at least one-half hour before the metabolism experiments are made. This restriction obtained in the Springfield experiments as well as in those made with the Harvard Medical School students. Consequently we may not ascribe the high value here to the element of novelty. From table 80 we see that unquestionably *Mon's* pulse-rate was perceptibly higher on this particular day than those obtained for other days, the pulse-rate for this day being 69 beats per minute as compared with 59 beats per minute two days before. It so happens that *Mon* was a well-trained man, who had done a great deal of wrestling and was dis-

[1] Published in abstract with data for members of Squad A by Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 234, table 91.

[2] Benedict and Smith, Journ. Biol. Chem., 1915, **20**, p. 243.

tinctly of an athletic type. He was somewhat older than the other men, and from his athletic training one might possibly expect a somewhat higher basal metabolism. His case, however, admirably illustrates the fact that an average normal basal metabolism from which individuals do not vary appreciably does not exist.

In analyzing the figures less than normal in the last column of table 113, we find that of these subjects *Can* was distinctly overweight and inclined to be fat, while *Tom* led by far the least athletic life of any man in the whole squad; both of these factors contribute, we believe, to lower the total metabolism. An explanation of the low values with *Bro* and *Vea* is not at hand.

A general inspection of the values in table 113, with the possible exception of *Mon*, leads one to believe that the subjects may be considered as normal individuals so far as their basal metabolism is concerned, with perhaps a slight tendency for an increase over the general average. While, as previously stated, this tendency to increase may be due to the fact that a relatively large number of these men were athletically inclined, it should also be noted that one of the most athletic was *Pea*, whose metabolism was but 43 calories above that predicted.

Before concluding the discussion of table 113 it is important to consider the variations in the heat per square meter of body-surface. The measurement of body-surface used for computing the heat production on this basis was made by means of the fully approved Du Bois height-weight chart and not based on the antiquated Meeh formula. The heat values thus computed range from 871 to 1,027 calories per square meter. The average value for all the men is 949 calories. Thus the metabolism of this squad of young healthy men, *i. e.*, a reasonably homogeneous group, falls within the plus or minus 10 per cent range.

The basal metabolism of these men is of special value in connection with this research, not only in showing whether or not it is within normal limits, but for use as a standard to which subsequent metabolism measurements may be referred, to note alterations that may be produced by restricted diet. It is especially unfortunate that the basal metabolism could not have been established in a longer period of observation. Since, however, an analysis of the values given in table 113 shows that we have here no distinctly abnormal basal-metabolism measurements, (unless those of *Mon* should be so considered), any subsequent metabolism measurements may properly be compared with the basal level as here recorded, particularly when the squad is considered as a group. It is perfectly possible, therefore, to refer the subsequent measurements of metabolism of any given individual to his original basal value.

GROUP MEASUREMENT OF RESTING METABOLISM, SQUADS A AND B.

While the individual measurements of the basal metabolism given in a previous section may be used as a base-line to which subsequent

values can be referred, we have also the heat output of the squad as a whole prior to diet restriction, which was obtained in the night experiments made with the Boston group respiration chamber in accordance with the previously described technique. (See p. 92.)

Measurements were made with both Squads A and B. These extremely trying experiments were carried on throughout the night with the special assistance of Miss Alice Johnson and with the intelligent cooperation of the Misses Inza A. Boles, Mildred A. Corson, Mary F. Hendry, Mary D. Finn, and on two nights, Mrs. Dorothy A. Peabody. In addition we wish to acknowledge the services of Mr. George L. Wall, whose care and fidelity in the preparation and testing of the large number of sulphuric-acid and soda-lime bottles made it possible for us to carry out this lengthy series of experiments without a single loss due to defective reagents or faulty containers.

With Squad A the results of only one night basal experiment are available, since it was necessary to begin the diet restriction shortly after this experiment was made. With Squad B the results of a number of night experiments are available, as the men were brought to Boston at intermittent periods prior to the beginning of the diet study with this squad the first week in January. Hence we have an exceptionally good measure of the basal metabolism of Squad B on normal diet. It is furthermore of importance to note that this represents the only measurement of the normal basal metabolism of Squad B, since individual metabolism measurements for basal values were not obtained with these men, *Ham* being the only man in Squad B who was thus studied. Likewise, subsequent to dietetic restriction, no individual respiratory exchange experiments were made with any member of Squad B. Hence our whole interpretation of the gaseous metabolism of this squad is based solely upon the measurements made with the group respiration chamber. The measurements of Squad A, however, supply supplementary evidence regarding the basal metabolism, and the changes in metabolism induced by restricted diet.

Unfortunately the personnel of Squads A and B changed somewhat from night to night. An ideal plan would have been to have had always the same individuals throughout the entire period. This was impossible for a number of reasons, as illness, the drafts for military service, and other calls away from college interfered more or less with the use of the men as subjects. Hence it is important for us to consider primarily in discussing the values obtained with the group respiration chamber the values per kilogram of body-weight and per square meter of body-surface. On these bases the values are, considering the homogeneity of the group, reasonably comparable. The total amounts measured are not comparable, owing to differences in personnel and differences in weight.

The gaseous-metabolism measurements of both Squads A and B in the large group respiration chamber are confined exclusively to the carbon-dioxide production. To compute the heat output from these values, it is necessary to assume a respiratory quotient. In the case of Squad A the respiratory quotient on the basal night is very properly assumed to be 0.81. This respiratory quotient was likewise used for Squad B for the night experiments in the respiration chamber prior to diet restriction. With both Squads A and B after the diet restriction respiratory quotients other than the basal must be assumed. These are usually obtained for Squad A from the measurements actually made with the respiratory-valve apparatus on the days nearest to the night in the group respiration chamber. The values must be assumed to apply likewise for Squad B at a corresponding period of weight reduction.

The values obtained for the minimum metabolism during sleep, as measured in the group respiration chamber prior to the period of reduced diet—*i. e.*, the basal values—for both Squads A and B are given in table 114, in which it can be seen that the values for Squad A are

TABLE 114.—*Minimum metabolism during sleep as measured in group respiration chamber prior to period of reduced diet.*

Squad and date.	Total body-weight without clothing.	Total body-surface (height-weight chart).	Carbon dioxide per hour.	Heat (computed) per hour.	
				Per kilo.	Per sq. meter.
	kg.	*sq. meters.*	*gm.*	*cals.*	*cals.*
Squad A:					
Sept. 29-30, 1917.	792	21.3	287	1.10	40.8
Squad B:					
Oct. 6- 7, 1917.	805	21.8	292	1.10	40.5
Nov. 3- 4, 1917.	814	21.9	295	1.10	40.7
Nov. 17-18, 1917.	815	21.9	292	1.08	40.3
Dec. 15-16, 1917.	818	21.9	287	1.06	39.6
Jan. 5- 6, 1918.	815	21.8	265	0.98	36.8

confined to the measurements on one night only (September 29–30) while for Squad B we have measurements for five nights. Although this table gives the total body-weight without clothing, total body-surface computed from the height-weight chart, and the total carbon-dioxide per hour, for comparative purposes we must rely solely upon the values given in the last two columns, namely, the heat per hour (computed) on the two bases of per kilogram and per square meter. These present several very interesting points. The average heat production per hour for Squad A was 1.10 calories per kilogram and 40.8 calories per square meter. From the normal values for the heat production per square meter per 24 hours obtained with the respiratory-valve apparatus and given in table 113, it can be computed that the average

heat production per square meter per hour for the squad was 39.5 calories. The slightly higher value obtained in the chamber may possibly be explained on the ground that it is not a true post-absorptive value, since the men had supper at 5 o'clock and the minimum metabolism was often found about 2 or 3 o'clock in the morning. To offset this we have the fact that the values were for the most part obtained during deep sleep. The agreement between the two values, 40.8 and 39.5 calories, may be said to be, on the whole, as close as one could expect.

The values found with Squad B are of special interest, for one of the chief reasons for using Squad B throughout this experiment at the expense of a large amount of time and labor, was not only to obtain a basal value for comparison, but to study possible seasonal variations in the various factors measured. As pointed out in an earlier section, when the men returned from their summer vacation, in the latter part of September, they came for the most part from Y.M.C.A. camps and active outdoor work. They immediately began an entirely new routine, living more or less indoors, studying late at night, and sleeping in the college dormitories. If there is, then, a normal seasonal variation in the metabolism, such studies as were made with Squad B would reveal it. The metabolism of Squad B as measured in the group respiration chamber throws considerable light upon this point. On October 6–7 (one week after the normal experiment with Squad A), Squad B showed a heat output per kilogram of body-weight and per square meter of body-surface of 1.10 and 40.5 calories, respectively, this being nearly identical with the values for Squad A normal. One month later, November 3–4, similar values were obtained. It thus appears from these measurements that the values found with Squad A were normal, and also that the number of men in the squad was sufficient to secure an average value. In other words, if Squad A had been twice as large on September 29–30, the heat per square meter and per kilogram per hour would not have altered in the slightest.

The subsequent course of the basal-metabolism measurements with Squad B is also of interest. On November 17–18 there was a fall of approximately 2 per cent in the metabolism. One month later, December 15–16, there was another fall of not far from 2 per cent. Using the values on October 6–7 as a basis, we have a fall in metabolism of about 4 per cent in the heat per kilogram and a little over 2 per cent in the heat per square meter of body-surface. Up to this point, one might reasonably and legitimately state that there was no seasonal variation in metabolism. On the night of January 5–6, prior to the day when the restricted diet was begun with Squad B, a last experiment was made inside the group respiration chamber to obtain the basal value. To our great surprise this showed a very considerable alteration in metabolism. The hourly heat per kilogram dropped to 0.98 calorie and per square meter of body-surface to 36.8 calories. Using

the values on October 7 and November 4 as basal values, we find here a fall of approximately 11 per cent in the heat production per kilogram of body-weight and about 9 per cent per square meter of body-surface. Of particular interest in this connection is the fact that these low values were found with Squad B on practically the first day on which they returned from their Christmas vacation. This is in distinct contrast to the values found with Squad A, which showed that both the pulse-rate and, as will subsequently be seen in the general basal-metabolism tables, the metabolism was considerably increased with all the men after returning from their vacation. This low caloric production of Squad B requires a critical examination of the metabolism measurements on this particular night.

In our effort to secure basal metabolism we have selected and reported in table 114 the values representing the minimum carbon-dioxide production per hour throughout the night. Most of the periods of experimentation throughout the night were from a half hour to an hour in length, and the values for the carbon-dioxide production here given are based upon the average of two or three and frequently more periods. Since there is, however, some discrimination permitted in the selection of the minimum period and an error in selection might profoundly affect the low value found, we have computed the average carbon-dioxide production for the measurements made throughout the night. The values for the minimum carbon-dioxide production per hour given in table 114 are naturally somewhat lower than the averages found for the entire night, being usually not far from 5 to 10 grams.[1] Thus, on the night of October 6–7 the total average carbon-dioxide production for Squad B was 297 as against a minimum of 292 gm.; on November 3–4, 297 as against 295 gm.; on November 17–18, 299 as against 292 gm.; on December 15–16, 296 as against 287 gm.; and what is of special interest, on the night of January 5–6, 276 as against 265 gm. Under these circumstances, it is perfectly clear that the value of 265 gm. is a probable minimum value and not an erroneous selection based upon one or two periods. On account of the construction of the group chamber and the fact that duplicate weighings are made in each period, there is almost no possibility of an error in the determination. Evidently, not only the minimum value but also the total carbon-dioxide production was at a distinctly lower level on this night than it had been on the previous occasions. Since the total body-weight of the group varied only from 805 to 818 kg., the values for the total carbon-dioxide production per hour on the different nights may properly be compared. An examination of the original protocols for this night shows no reason whatever for questioning these results.

Among other explanations for this variation in metabolism found with Squad B we have considered the change in temperature environ-

[1] For detailed values of a typical night, see table 5, page 119.

ment. As the season progressed the weather became colder, but the temperatures inside of the group respiration chamber on these nights give no suggestion of change in temperature environment during the various experiments. Furthermore, no evidence has as yet been obtained to show an influence of small changes in temperature environment upon normally-clothed men. The widest variation in average temperatures throughout the entire season's experiments was but 4° C.; the average temperature for January 5–6 was 19.3°. We thus have here a perceptible lowering in the basal metabolism for which we have no satisfactory explanation.[1]

Heretofore it has been assumed that the basal metabolism is constant,[2] particularly when average values are considered, but this group of 12 men, with only minor changes in personnel, showed on the average an actual decrease in the metabolism per kilogram of body-weight amounting to about 11 per cent and a lowering of the metabolism per square meter of body-surface amounting to 9 per cent, in the period from November 4 to January 6. We have no means of knowing to what extent this fall in metabolism is a normal procedure, nor have we evidence as to whether Squad A would have shown a similar lowering, but we must consider the possibilities of having to deal with a normal seasonal fall in basal metabolism of 11 per cent, on the basis of body-weight, or 9 per cent on the basis of body-surface. In any event the value for January 5–6 must be considered as the basal value for Squad B for subsequent comparison.

To sum up these findings regarding the basal metabolism of Squads A and B, we may say, first, that in the early part of October the two squads gave identical results for heat production in the group respiration chamber both per kilogram of body-weight and per square meter of body-surface. The average basal value for Squad A determined with the respiration apparatus in Springfield (see table 113) was 39.5 calories, which was but 3 per cent lower than that found with the group respiration chamber in Boston. We thus have three indices of uniformity in the basal values for these squads. Second, the fact that Squad B gave identical values with Squad A indicates that the number of men in the squad was sufficiently large for a general average result. Third, and most difficult to interpret, is the fact that, after 4 weeks of constancy, there was a slight seasonal variation in the metabolism, with a tendency towards a decrease in metabolism from

[1] The experiment on the night of January 5 immediately followed the Christmas vacation, the men coming direct from their homes to the Laboratory. The train travel, and the unusual social activities engaged in during the previous 18 days, with consequent loss of sleep, produced fatigue and probably a deeper sleep during the night experiment. The possible factors of fatigue and depth of sleep thus entered into this experiment as in no other one in this series. Attention must be called to the fact that psychological observations on January 5 show, in general, aberrant values which may logically be ascribed to this factor of fatigue. A further complicating feature is the fact that the pulse-rate on the morning of January 6 was, as a matter of fact, 3 beats higher than the last observation on the morning of December 16. This would lead us to expect an increase rather than a decrease in metabolism.

[2] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918.

November 4 until December 16, which amounted to 3 per cent, and a profound lowering of metabolism on January 6, which amounted to 11 per cent per kilogram of body-weight and 9 per cent per square meter of body-surface over the values obtained in the early autumn.

BASAL METABOLISM DURING DIET RESTRICTION.

For an index of the influence of diet restriction upon the caloric needs we have taken the basal metabolism, *i. e.*, the values obtained with the subject lying quietly, in the post-absorptive condition, since this represents the larger proportion of the total caloric needs for the day. Using precisely the same technique as for the preliminary observation, we determined the basal metabolism nearly every day for members of Squad A throughout the entire period of experimentation, except during the vacations at Thanksgiving and at Christmas.

INDIVIDUAL MEASUREMENTS OF BASAL METABOLISM WITH LOW DIET, SQUAD A.

The data for the individual members of Squad A for the respiratory exchange during the period of diet restriction, also the computed heat output are collected in tables 115 to 127 inclusive, so that it is possible to trace the course of the respiratory exchange and the basal heat production from day to day throughout the entire experimental period. These values are reported here primarily as oxygen consumption per minute, the carbon-dioxide values being omitted to save space. The respiratory quotient, whenever given, indicates that the experiment was made for that particular day with the respiratory-valve apparatus. On other days the experiments were made with the portable respiration apparatus. Obviously, if desired, the carbon-dioxide output may be readily computed from the oxygen consumption and the respiratory quotient. The pulse-rates are not included in these tables, as they appear in detail in the discussion of the pulse rate. (See p. 384.) The total heat production per 24 hours, the heat per kilogram of body-weight per 24 hours, and the heat per square meter of body-surface per 24 hours are given in these tables. These data give a clear picture for each individual in Squad A of the influence of the restricted diet upon the basal metabolism.

An inspection of the individual gaseous-metabolism tables for each subject shows a great reduction in the total heat production per 24 hours from the beginning to the end of the experiment. This is true with all of the men in Squad A. The reduction in weight averaged not far from 10 per cent. The reduction in the total heat production was considerably more than 10 per cent. Hence we should expect to find a lowering of the heat production per kilogram of body-weight and likewise of the heat production per square meter of body-surface. The values for the heat production on these two bases are recorded in the last two columns of the individual metabolism tables. A superficial inspection of the data for *Bro* implies that the heat produc-

tion per kilogram of body-weight was essentially the same at the beginning and end of the experiment, but the tables for the other subjects show that there is, with many, a distinct decrease in the heat production per kilogram of body-weight. High values are occasionally found, but, as will be subsequently shown, these are for the most part attributable to excess eating on either the uncontrolled days or during the holidays.

TABLE 115—*Basal metabolism of George A. Brown—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 29	215	0.70	1,502	24.3	884	Nov. 21	184	0.75	1,256	22.2	771
Oct. 1	208	......	1,452	23.5	854	23	186	......	1,269	22.7	783
3	220	......	1,536	24.9	904	24	199	......	1,358	24.3	838
4	205	......	1,433	23.2	843	26	192	......	1,310	23.7	809
Reduced.						28	197	......	1,344	23.9	825
Oct. 5	210	0.84	1,467	23.7	863	Dec. 3	203	......	1,385	24.6	850
7	208	......	1,434	23.4	849	4	186	......	1,269	22.7	779
8	201	......	1,386	22.6	820	6	181	......	1,235	22.1	758
9	190	......	1,310	21.3	775	7	186	......	1,269	23.1	788
11	201	0.74	1,368	22.3	809	8	186	0.75	1,269	23.1	788
12	202	......	1,379	22.5	816	11	179	......	1,225	22.3	761
13	214	......	1,460	23.8	864	12	192	......	1,314	23.9	816
16	199	0.75	1,358	22.3	804	13	199	......	1,362	25.0	846
18	202	......	1,379	22.6	816	15	177	0.77	1,214	22.2	754
20	209	......	1,426	23.4	844	16	186	......	1,279	23.3	794
22	200	......	1,365	22.7	813	18	176	0.78	1,211	22.2	752
24	203	......	1,385	23.0	824	19	193	......	1,324	24.2	822
25	198	......	1,351	22.5	804	1918.					
26	194	0.74	1,320	22.0	786	Jan. 8	206	......	1,413	24.8	862
27	204	......	1,392	23.2	829	9	201	......	1,379	24.2	841
30	203	......	1,385	23.4	829	11	195	0.75	1,331	23.6	817
31	202	......	1,379	23.3	826	12	190	......	1,307	23.3	802
Nov. 3	202	......	1,379	23.4	831	15	178	0.80	1,231	22.0	755
6	219	......	1,494	25.6	900	16	190	......	1,310	23.6	809
7	197	......	1,344	23.1	810	18	186	......	1,282	23.1	791
8	187	0.75	1,276	22.2	778	19	177	0.77	1,214	22.0	749
10	202	......	1,382	24.0	838	21	175	......	1,200	21.6	741
12	194	......	1,327	23.3	809	23	165	0.76	1,129	20.4	697
13	188	......	1,286	22.6	784	24	176	......	1,207	21.9	750
15	187	0.77	1,283	22.5	782	26	165	0.78	1,135	20.6	705
16	198	......	1,355	23.8	826	29	175	......	1,207	22.0	750
17	199	......	1,362	23.9	830	30	183	......	1,262	23.0	784
19	193	......	1,321	23.4	810	Feb. 1	184	0.79	1,269	23.3	788
20	196	......	1,341	23.7	823	2	186	......	1,282	23.3	796

[1] The experiments reported in this table and in tables 116 to 127 were made with the portable respiration apparatus and the respiratory-valve apparatus. The subject was in all cases in the lying position and had been without food for at least 12 hours. Respiratory quotients were obtained with the respiratory-valve apparatus and have been used in computing the heat on the days when they were determined. On the remaining days (with the portable respiration apparatus) quotients were interpolated for the heat computations. No respiratory quotient below 0.73 has been used in the calculations.

TABLE 116.—*Basal metabolism of Kenneth B. Canfield—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).	Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 27	266	0.75	1,814	22.7	921	Nov. 21	241	......	1,670	23.7	893
29	243	......	1,680	21.1	853	22	228	......	1,580	22.4	845
Oct. 1	250	......	1,728	21.7	877	24	216	......	1,497	21.3	801
2	261	......	1,804	22.6	916	26	223	......	1,546	22.1	831
4	253	0.84	1,766	22.1	896	27	228	0.83	1,589	22.4	850
Reduced.						Dec. 3	238	......	1,645	23.2	880
Oct. 5	252	......	1,742	21.8	884	4	240	......	1,659	23.4	887
6	263	......	1,819	22.8	923	5	236	......	1,632	23.0	873
8	259	......	1,790	22.7	913	7	225	0.76	1,541	22.2	829
9	295	......	1,790	22.7	913	8	228	......	1,576	22.7	847
10	251	0.72	1,735	22.0	885	10	223	......	1,542	22.3	834
12	250	......	1,728	21.9	882	12	228	......	1,576	22.5	847
13	266	......	1,838	23.3	938	13	239	......	1,652	23.6	888
15	256	......	1,769	22.7	907	14	227	0.83	1,581	22.6	850
17	251	......	1,735	22.3	890	16	228	......	1,584	23.0	856
19	253	......	1,750	22.5	897	17	232	......	1,612	23.1	867
21	255	......	1,764	23.1	914	18	231	......	1,605	23.0	863
23	260	......	1,798	23.6	932	1918.					
25	240	0.76	1,642	21.5	851	Jan. 7	251	0.81	1,740	23.8	916
26	248	......	1,701	22.3	881	8	255	......	1,759	24.1	926
29	259	......	1,777	23.8	930	9	265	......	1,827	25.7	977
31	250	......	1,715	22.9	898	10	258	......	1,779	24.8	946
Nov. 3	250	......	1,715	23.5	903	11	245	0.76	1,678	23.6	897
4	242	......	1,660	22.8	874	12	242	......	1,669	23.5	893
5	245	......	1,681	23.1	885	15	221	0.81	1,531	21.4	814
7	232	0.78	1,596	21.9	840	16	243	......	1,671	23.4	889
8	237	......	1,622	22.5	858	18	239	......	1,644	23.4	879
9	233	......	1,594	22.1	843	19	226	0.75	1,543	21.8	825
12	222	......	1,519	21.4	812	21	228	......	1,564	22.0	836
13	232	......	1,588	22.4	849	22	219	0.79	1,510	21.4	807
14	226	0.73	1,534	21.6	820	26	225	0.79	1,553	21.9	830
16	244	......	1,670	23.4	888	29	229	......	1,583	22.2	842
17	233	......	1,594	22.3	848	30	231	......	1,597	22.7	854
18	234	......	1,601	22.7	856	Feb. 2	230	0.80	1,591	22.6	850
20	222	0.79	1,531	21.7	819						

TABLE 117.—*Basal metabolism of Lester F. Fretter—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).	Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 29	228	......	1,564	27.2	954	Oct. 9	234	......	1,609	28.2	981
Oct. 1	241	......	1,653	28.7	1,008	11	227	0.78	1,562	27.4	952
2	215	0.77	1,476	25.7	900	12	231	......	1,585	27.8	966
3	236	......	1,623	28.2	990	13	215	......	1,475	25.9	899
4	237	......	1,630	28.3	994	16	222	......	1,523	27.0	934
Reduced.						18	220	0.76	1,505	26.6	923
Oct. 5	224	0.78	1,541	26.8	940	20	218	......	1,492	26.4	915
7	234	......	1,609	28.2	981	22	210	......	1,437	25.4	882
8	233	......	1,602	28.1	977	23	219	......	1,499	26.5	920

TABLE 118.—*Basal metabolism of Everett R. Kontner—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Oct. 27	267	0.79	1,841	26.7	1,034	Nov. 28	210	0.79	1,447	22.4	832
29	260	0.79	1,793	26.0	1,007	Dec. 5	225	0.81	1,560	24.4	902
30	264	0.79	1,821	26.4	1,023	6	232	......	1,604	25.1	927
Reduced.						12	212	......	1,466	23.3	852
Oct. 31	257	......	1,763	25.6	990	15	232	0.79	1,601	25.8	936
Nov. 2	251	0.75	1,714	25.3	968	16	228	......	1,572	25.4	919
3	260	......	1,784	26.3	1,008	17	209	......	1,441	23.2	843
4	246	0.78	1,692	25.2	961	19	206	......	1,421	23.1	836
6	240	0.73	1,630	24.3	926	1918.					
7	239	......	1,627	24.2	924	Jan. 12	242	0.78	1,663	25.3	950
8	240	0.74	1,634	24.4	928	14	232	......	1,596	24.2	912
10	220	......	1,501	22.4	853	15	239	0.77	1,639	25.2	942
12	221	......	1,508	23.1	867	17	227	......	1,553	24.1	892
13	214	......	1,460	22.4	839	18	235	0.74	1,601	25.0	925
15	245	0.76	1,678	25.6	959	19	233	......	1,598	25.0	924
16	227	......	1,553	23.7	887	22	207	0.80	1,430	22.6	831
17	219	......	1,499	22.9	857	23	226	......	1,559	24.7	906
19	205	......	1,403	21.7	806	24	218	......	1,503	23.9	874
20	221	......	1,512	23.3	869	26	201	0.78	1,382	22.1	808
21	214	0.75	1,459	22.4	839	29	202	......	1,396	22.3	816
23	209	......	1,434	22.0	824	31	203	0.82	1,411	22.6	825
24	201	......	1,379	21.1	793	Feb. 2	213	......	1,480	23.7	865
26	225	......	1,544	24.1	892						

TABLE 119.—*Basal metabolism of Greyson C. Gardner—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 27	271	0.79	1,870	26.2	1,022	Oct. 23	221	0.75	1,507	22.1	837
Oct. 2	273	......	1,887	26.5	1,031	24	232	......	1,583	23.2	879
4	244	0.80	1,687	23.7	922	25	237	......	1,617	23.7	898
Reduced.						26	241	......	1,645	24.1	914
Oct. 5	256	......	1,761	24.7	962	27	229	......	1,563	22.9	868
9	239	......	1,644	23.3	903	30	220	......	1,501	22.5	839
10	239	0.76	1,634	23.2	898	31	236	......	1,610	24.1	899
12	258	......	1,765	25.0	970	Nov. 1	220	0.75	1,502	22.7	844
13	268	......	1,834	26.0	1,008	4	222	......	1,523	23.4	860
15	215	......	1,471	21.1	808	5	220	......	1,509	23.2	853
17	243	0.76	1,663	23.8	914	7	219	0.78	1,507	23.1	851
19	226	......	1,547	22.2	850	8	239	......	1,640	25.2	932
21	227	......	1,553	22.7	863	9	222	......	1,523	23.4	865

TABLE 119.—*Basal metabolism of Greyson C. Gardner—Squad A*—continued.

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).	Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Reduced.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Nov. 12	228	......	1,564	24.3	889	Dec. 16	212	......	1,466	23.5	843
13	210	......	1,441	22.4	819	17	215	......	1,486	23.4	849
14	211	0.75	1,440	22.4	818	18	214	......	1,479	23.3	845
16	223	......	1,522	23.5	865	1918.					
17	220	......	1,501	23.2	853	Jan. 7	264	......	1,825	26.7	1,014
18	222	......	1,515	23.7	861	9	255	......	1,763	26.2	985
20	209	0.74	1,423	22.2	813	10	237	0.75	1,618	24.2	904
21	222	......	1,511	23.6	863	12	248	......	1,719	26.3	971
22	225	......	1,532	23.9	875	14	223	0.87	1,570	23.3	877
24	218	......	1,484	23.3	848	15	228	......	1,580	23.9	888
28	211	0.74	1,435	22.6	820	17	218	......	1,511	23.2	859
Dec. 3	216	......	1,470	23.1	840	18	230	0.75	1,570	24.5	897
4	221	......	1,504	23.9	864	20	217	......	1,485	23.5	849
5	218	......	1,484	23.6	853	22	194	0.76	1,327	20.5	754
7	205	0.74	1,394	22.2	801	23	215	......	1,471	22.7	836
8	207	......	1,427	22.7	820	25	203	0.76	1,390	21.9	794
10	235	......	1,621	26.0	937	26	205	......	1,406	22.2	803
12	213	......	1,469	23.6	849	29	211	......	1,447	22.6	827
13	213	......	1,469	23.6	849	31	200	0.77	1,373	21.4	780
14	202	0.84	1,411	22.6	816	Feb. 1	223	......	1,530	23.5	869

TABLE 120.—*Basal metabolism of Otto A. Gullickson—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).	Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 28	228	......	1,591	23.8	914	Oct. 23	236	......	1,627	25.2	946
Oct. 1	249	0.84	1,740	26.0	994	24	232	......	1,601	24.8	931
3	254	......	1,764	26.4	1,014	26	229	......	1,579	24.5	918
Reduced.						29	221	......	1,524	24.1	891
Oct. 5	251	......	1,745	26.1	1,003	31	220	0.81	1,524	24.1	891
7	241	0.80	1,666	25.1	957	Nov. 2	239	......	1,656	26.4	974
8	224	......	1,546	23.3	889	3	222	......	1,538	24.5	905
9	246	......	1,697	25.6	975	4	224	0.81	1,553	25.0	919
11	256	......	1,766	26.6	1,015	6	219	......	1,517	24.5	898
12	266	......	1,834	27.7	1,054	7	210	......	1,454	23.5	860
13	235	0.77	1,613	24.3	927	8	218	......	1,512	24.6	895
16	242	......	1,656	25.2	952	10	207	0.81	1,435	23.3	849
18	245	......	1,678	25.5	964	12	230	......	1,586	26.2	944
20	228	0.75	1,555	23.6	894	13	201	......	1,387	22.9	831
21	244	......	1,670	25.9	971	15	209	......	1,442	23.5	858
22	221	0.76	1,512	23.4	879	16	216	......	1,490	24.3	887

TABLE 120.—*Basal metabolism of Otto A. Gullickson—Squad A*—continued.

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Reduced.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Nov. 17	213	0.77	1,462	23.9	870	Dec. 18	204	......	1,414	23.8	852
19	196	......	1,349	22.3	803	19	200	......	1,387	23.3	836
20	198	......	1,361	22.5	810	1918.					
21	193	......	1,327	21.9	790	Jan. 7	213	......	1,476	24.6	884
22	203	......	1,397	23.1	832	9	215	0.79	1,483	23.4	867
23	198	0.79	1,366	22.4	813	10	231	......	1,610	25.6	947
26	259	......	1,795	29.8	1,075	12	218	......	1,519	24.4	894
27	208	0.83	1,450	24.0	868	14	240	0.87	1,690	26.5	988
Dec. 3	202	......	1,392	23.1	834	15	195	......	1,358	21.6	799
4	214	0.74	1,457	24.7	878	17	218	......	1,519	24.7	899
6	222	......	1,546	26.2	931	18	223	0.72	1,553	25.7	924
7	221	......	1,541	25.5	917	20	208	......	1,450	24.2	868
8	223	......	1,553	25.7	924	21	184	0.78	1,265	20.9	753
11	197	0.91	1,399	23.0	833	25	192	0.80	1,327	21.8	790
12	202	......	1,421	23.5	846	26	185	......	1,277	21.2	765
13	207	......	1,457	24.3	872	30	192	......	1,325	21.9	789
15	194	......	1,366	23.0	823	31	200	0.78	1,375	22.7	818
17	193	0.83	1,344	22.6	810	Feb. 1	230	......	1,582	26.4	947

TABLE 121.—*Basal metabolism of Kirk G. Montague—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 29	273	0.74	1,858	27.0	1,027	Nov. 1	235	......	1,615	25.2	923
Reduced.						3	226	0.68	1,555	24.3	889
Oct. 6	264	0.78	1,817	26.4	1,004	4	231	......	1,589	25.2	913
8	255	......	1,750	25.7	972	5	236	......	1,622	25.7	932
9	252	......	1,728	25.4	960	7	228	......	1,567	24.9	901
10	244	......	1,673	24.6	929	8	228	......	1,567	24.9	901
12	260	0.76	1,778	26.1	988	9	218	0.75	1,488	23.6	855
13	250	......	1,711	25.2	951	12	213	......	1,462	23.7	845
15	229	......	1,567	23.3	875	13	217	......	1,488	24.1	860
17	253	......	1,730	25.7	967	14	226	......	1,550	25.1	896
19	263	0.75	1,795	26.7	1,003	16	236	0.79	1,627	26.3	940
21	241	0.80	1,666	25.3	941	17	220	......	1,522	24.5	880
22	239	......	1,644	25.0	929	18	230	......	1,591	25.7	920
24	241	......	1,658	25.2	937	20	227	......	1,570	25.5	913
25	244	......	1,678	25.5	948	21	229	......	1,584	25.8	921
27	254	......	1,747	26.6	987	22	231	0.80	1,596	26.0	928
29	227	......	1,560	24.3	886	23	221	......	1,550	25.2	901
30	214	......	1,471	22.9	836	26	218	......	1,531	25.1	890

TABLE 121.—*Basal metabolism of Kirk G. Montague—Squad A*—continued.

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).	Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Reduced.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1918.					
Nov. 27	229	......	1,608	26.0	929	Jan. 8	254	......	1,764	28.8	1,026
Dec. 3	222	0.92	1,582	25.6	914	10	225	0.75	1,536	25.0	893
5	226	......	1,606	26.0	928	11	231	......	1,606	25.7	923
6	231	......	1,642	26.6	949	14	217	0.88	1,531	24.5	880
7	228	......	1,620	26.9	947	15	235	......	1,632	26.6	949
8	223	......	1,584	26.3	926	17	217	0.76	1,486	24.2	864
10	244	0.89	1,726	28.9	1,015	19	225	......	1,555	25.3	904
12	231	......	1,634	26.9	956	20	228	......	1,577	25.9	922
13	228	......	1,613	26.5	943	21	231	0.84	1,613	26.4	938
14	209	......	1,478	24.3	864	23	233	......	1,610	26.4	936
16	210	0.89	1,486	24.4	864	25	212	0.75	1,447	23.7	841
17	222	......	1,543	25.7	908	26	226	......	1,555	25.5	904
18	210	......	1,459	24.3	858	30	225	0.81	1,560	26.0	918
1918.						Feb. 1	219	......	1,517	25.0	887
Jan. 7	247	......	1,716	28.0	998						

TABLE 122.—*Basal metabolism of Henry A. Moyer—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).	Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 27	243	......	1,702	26.8	962	Oct. 31	218	......	1,495	24.5	859
28	236	......	1,654	26.0	934	Nov. 1	218	......	1,495	24.6	859
Oct. 1	209	0.85	1,464	23.1	827	4	210	......	1,440	24.0	832
3	250	......	1,733	27.3	979	5	210	......	1,440	24.0	832
Reduced.						6	194	......	1,332	22.2	770
Oct. 5	232	......	1,608	25.3	909	8	219	......	1,502	25.2	873
6	250	......	1,733	27.3	979	9	206	......	1,414	23.8	822
7	232	0.76	1,586	25.1	901	10	209	0.77	1,433	24.1	833
9	262	......	1,793	28.4	1,019	13	201	......	1,375	23.5	804
10	234	......	1,601	25.4	910	14	203	......	1,390	23.8	813
11	246	......	1,682	26.7	956	15	208	......	1,423	23.9	827
13	224	0.76	1,534	24.3	872	17	202	0.74	1,375	23.1	799
16	240	......	1,646	26.2	935	18	211	......	1,440	24.7	847
18	236	......	1,620	25.8	920	19	207	......	1,414	24.3	832
19	244	......	1,673	26.6	951	21	203	......	1,385	23.8	815
20	224	0.77	1,536	24.5	873	22	194	......	1,325	22.7	779
21	228	......	1,565	25.3	894	23	194	0.75	1,325	22.9	779
22	240	......	1,646	26.6	941	26	217	......	1,486	26.1	879
24	232	......	1,591	25.7	909	27	194	......	1,327	22.9	781
26	222	......	1,524	24.6	871	28	188	......	1,286	22.2	756
30	222	......	1,524	25.0	876	Dec. 4	202	0.76	1,382	24.2	818

TABLE 122.—*Basal metabolism of Henry A. Moyer—Squad A*—continued.

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Reduced.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1918.					
Dec. 5	209	......	1,445	25.4	855	Jan. 9	229	0.77	1,572	25.8	903
6	208	......	1,438	25.2	851	10	238	......	1,630	27.0	942
8	206	......	1,423	25.0	842	11	223	......	1,526	25.4	882
10	236	......	1,632	28.9	971	16	210	......	1,438	24.2	836
11	188	0.83	1,310	23.0	775	17	218	0.74	1,483	25.1	867
13	211	......	1,466	25.6	867	19	200	......	1,373	23.9	812
14	200	......	1,390	24.3	822	20	194	0.79	1,337	22.9	782
15	206	......	1,430	25.3	851	22	201	......	1,387	23.9	816
16	198	......	1,375	24.3	818	24	198	0.78	1,361	23.3	801
17	196	0.81	1,358	24.3	813	25	199	......	1,375	24.3	818
19	206	......	1,421	24.7	841	28	188	......	1,301	22.3	765
1918.						30	191	0.81	1,325	22.8	779
Jan. 8	249	......	1,716	28.1	986	Feb. 2	197	......	1,366	23.2	799

TABLE 123.—*Basal metabolism of Allen S. Peabody—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 28	266	......	1,844	26.6	1,030	Nov. 1	210	......	1,452	22.9	839
29	253	0.81	1,754	25.3	980	2	203	......	1,403	22.1	811
Oct. 2	248	......	1,719	24.8	960	3	201	0.80	1,390	21.9	803
3	255	......	1,767	25.5	987	5	208	......	1,438	22.9	836
4	252	......	1,747	25.2	976	6	215	......	1,486	23.7	864
Reduced.						7	195	......	1,348	21.5	784
Oct. 6	243	0.80	1,680	24.2	939	9	204	0.80	1,411	22.6	820
7	240	......	1,655	24.3	930	10	199	......	1,379	22.1	802
8	257	......	1,772	26.1	996	12	194	......	1,345	21.9	787
10	230	......	1,586	23.3	891	14	197	......	1,365	22.3	798
11	242	......	1,669	24.5	939	15	201	......	1,393	22.4	810
12	238	0.78	1,637	24.1	920	16	194	0.81	1,344	21.6	781
15	219	......	1,510	22.6	853	18	204	......	1,414	23.0	827
17	228	......	1,572	23.5	888	19	197	......	1,365	22.2	798
19	216	0.80	1,493	22.4	844	20	203	......	1,407	22.7	823
20	226	......	1,562	23.4	882	22	192	0.80	1,327	21.4	776
21	221	......	1,528	23.4	873	23	197	......	1,372	22.3	802
22	214	......	1,479	22.6	845	24	198	......	1,379	22.4	806
23	221	......	1,528	23.4	873	27	194	......	1,352	21.6	786
25	208	......	1,438	22.0	822	28	198	......	1,379	22.1	802
27	224	......	1,549	23.7	885	Dec. 3	209	0.86	1,466	23.5	852
29	227	......	1,569	24.6	902	4	204	......	1,446	23.5	846
31	200	......	1,383	21.7	795	6	195	......	1,383	22.5	809

TABLE 123.—*Basal metabolism of Allen S. Peabody—Squad A*—continued.

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Reduced.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1918.					
Dec. 7	194	......	1,376	22.4	805	Jan. 10	223	......	1,534	24.2	887
10	205	0.93	1,464	24.1	861	12	214	0.76	1,464	23.2	846
11	192	......	1,358	21.7	790	16	221	......	1,512	24.3	879
12	202	......	1,429	23.2	836	17	201	0.76	1,375	21.9	799
13	195	0.85	1,366	22.1	799	19	211	......	1,447	23.2	841
14	194	......	1,352	21.9	791	20	190	0.78	1,306	21.1	764
15	199	......	1,386	22.4	811	22	194	......	1,331	21.4	774
16	197	0.81	1,366	22.1	799	24	187	0.75	1,277	20.8	747
19	193	......	1,334	21.7	780	25	198	......	1,358	22.1	794
1918.						28	197	......	1,351	22.0	790
Jan. 7	230	......	1,590	23.6	893	30	183	0.78	1,258	20.6	740
8	209	0.79	1,442	21.4	810	Feb. 1	185	0.79	1,277	20.9	751

TABLE 124.—*Basal metabolism of R. Wallace Peckham—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 27	231	......	1,593	24.8	910	Nov. 5	205	......	1,403	23.0	821
28	230	......	1,586	24.7	906	6	188	0.74	1,279	21.0	748
Oct. 1	212	......	1,462	22.7	835	8	183	......	1,252	20.7	736
2	260	......	1,793	27.9	1,024	9	200	......	1,369	22.6	805
3	219	0.79	1,510	23.5	863	10	190	......	1,300	21.5	765
Reduced.						13	188	0.77	1,289	21.6	763
Oct. 5	267	......	1,832	28.5	1,047	14	199	......	1,365	22.8	808
6	253	......	1,736	27.0	992	15	194	......	1,331	21.9	778
7	258	......	1,770	27.7	1,017	17	192	......	1,317	21.7	770
9	231	0.75	1,576	24.7	906	18	182	......	1,249	20.5	730
10	207	......	1,416	22.2	814	19	183	0.76	1,253	20.6	733
11	225	......	1,540	24.1	885	21	187	......	1,299	21.5	764
13	236	......	1,615	25.3	928	23	183	......	1,271	21.2	748
15	240	......	1,642	25.9	944	24	177	......	1,230	20.5	724
17	254	......	1,738	27.4	999	26	208	0.88	1,469	24.7	869
18	216	0.76	1,478	23.3	849	27	186	......	1,302	21.8	770
22	252	......	1,733	27.7	1,002	28	188	......	1,316	22.0	779
24	206	0.80	1,423	22.8	823	Dec. 4	189	......	1,323	22.4	788
26	223	......	1,549	24.8	895	5	194	......	1,359	23.0	809
29	242	0.84	1,690	27.5	988	6	180	0.81	1,248	21.2	743
30	221	......	1,532	24.9	896	8	187	......	1,296	22.0	771
Nov. 1	200	......	1,386	22.6	811	10	215	......	1,490	25.8	892
2	193	0.78	1,327	21.6	776	11	191	......	1,324	22.1	783
4	200	......	1,369	22.4	801	12	180	0.81	1,248	21.2	743

TABLE 124.—*Basal metabolism of R. Wallace Peckham—Squad A*—continued.

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).	Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).
Reduced.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1918.					
Dec. 14	189	......	1,310	22.2	780	Jan. 16	186	0.75	1,270	21.8	756
15	184	......	1,275	21.8	759	17	181	......	1,242	21.2	739
17	190	......	1,317	22.7	789	21	176	0.78	1,210	20.5	720
19	182	0.80	1,258	21.7	753	22	176	......	1,214	20.6	723
1918.						24	177	0.79	1,222	20.9	727
Jan. 7	203	0.72	1,397	23.7	832	25	174	......	1,203	20.5	716
8	189	......	1,301	22.1	774	28	173	......	1,196	20.3	712
9	205	......	1,409	23.6	834	29	170	0.81	1,178	20.0	701
11	191	......	1,313	22.3	782	Feb. 2	185	0.79	1,277	21.6	760
14	171	......	1,176	19.5	692						

TABLE 125.—*Basal metabolism of Wesley G. Spencer—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).	Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 28	219	......	1,510	23.8	863	Nov. 3	210	......	1,448	24.6	857
29	275	......	1,896	29.9	1,083	5	208	0.80	1,438	24.8	856
Oct. 2	231	0.79	1,594	25.1	911	6	199	......	1,390	23.9	827
3	277	......	1,905	30.0	1,089	7	180	......	1,257	21.6	748
4	256	......	1,761	27.7	1,006	9	206	......	1,439	24.8	857
Reduced.						10	199	......	1,390	24.0	827
Oct. 6	247	......	1,699	26.8	971	12	198	0.87	1,394	24.8	840
7	229	......	1,575	25.2	905	14	199	......	1,386	24.6	835
8	242	0.77	1,660	26.5	954	15	208	......	1,449	25.2	868
10	231	......	1,597	25.5	918	16	202	......	1,407	24.5	843
11	237	......	1,638	26.2	941	18	193	0.78	1,327	23.5	799
12	248	......	1,715	27.4	986	19	184	......	1,265	22.4	762
17	220	0.82	1,529	24.7	884	22	191	......	1,314	23.3	792
18	238	......	1,637	26.5	946	23	191	......	1,314	23.1	792
19	245	......	1,685	27.3	974	24	186	0.78	1,279	22.5	770
21	221	......	1,520	25.2	869	27	197	......	1,351	23.4	804
23	211	0.74	1,436	23.8	840	28	191	......	1,310	22.7	780
25	228	......	1,564	25.9	915	Dec. 3	201	......	1,379	23.9	821
27	[1]256	......	[1]1,756	[1]29.1	[1]1,027	6	195	......	1,338	23.7	806
30	213	0.80	1,474	25.0	872	7	196	......	1,345	23.6	805
31	241	......	1,662	28.2	983	8	187	0.76	1,279	22.4	766
Nov. 1	208	0.78	1,430	24.3	846	10	204	......	1,396	25.2	851
2	205	......	1,414	24.0	837	11	206	......	1,410	25.2	855

[1]On Oct. 27 *Spe* believed he had a touch of grippe. His oral temperature was 98.8° F. and average pulse-rate, 68.

TABLE 126.—*Basal metabolism of Leslie J. Tompkins—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).	Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours. Total.	Heat (computed) per 24 hours. Per kg. of body-weight.	Heat (computed) per 24 hours. Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 27	219	......	1,526	25.6	882	Nov. 15	192	......	1,327	23.4	781
28	246	......	1,714	28.8	991	17	197	......	1,361	24.0	801
Oct. 1	204	......	1,421	23.9	821	18	191	......	1,320	23.7	786
2	222	......	1,546	26.0	894	19	177	0.77	1,214	21.8	723
3	204	0.83	1,421	23.9	821	21	185	......	1,301	23.2	770
Reduced.						22	188	......	1,322	23.6	782
Oct. 5	215	......	1,486	25.0	859	24	185	......	1,301	23.3	774
6	223	......	1,541	25.9	891	26	182	0.97	1,313	23.5	782
7	223	......	1,541	26.0	891	27	174	......	1,224	21.7	724
9	224	0.77	1,536	25.9	888	Dec. 4	201	......	1,414	25.3	837
10	211	......	1,452	24.4	839	5	201	......	1,414	25.3	837
11	224	......	1,541	25.9	891	6	181	0.76	1,238	22.1	733
13	216	......	1,486	25.0	859	8	186	......	1,272	22.8	757
15	239	......	1,644	27.7	950	10	197	......	1,349	24.4	803
16	204	0.78	1,404	23.7	812	11	193	......	1,320	23.6	781
18	217	......	1,498	25.3	866	13	187	0.76	1,279	22.9	761
20	210	......	1,447	24.4	836	14	200	......	1,368	24.5	814
22	207	0.79	1,428	24.3	830	15	192	......	1,313	23.7	782
24	202	......	1,390	23.6	808	17	192	......	1,313	23.7	782
26	216	......	1,486	25.3	864	19	169	0.76	1,157	20.9	689
27	220	......	1,512	25.7	879	1918.					
29	221	......	1,519	26.1	883	Jan. 12	198	0.80	1,368	24.3	809
31	191	0.76	1,308	22.4	760	14	194	......	1,332	23.4	784
Nov. 1	204	......	1,406	24.3	822	16	194	0.74	1,320	23.8	786
2	211	......	1,454	25.2	850	18	209	......	1,426	25.8	849
4	217	......	1,498	26.2	881	20	180	0.75	1,229	22.3	736
5	202	......	1,392	24.3	819	21	195	......	1,342	24.3	799
6	196	......	1,351	23.6	795	22	197	......	1,356	24.4	807
8	206	......	1,421	24.9	836	23	172	0.80	1,188	21.4	707
9	197	......	1,358	23.8	799	25	187	......	1,294	23.5	775
10	204	......	1,406	24.7	827	28	171	......	1,183	21.5	708
13	173	0.82	1,202	21.3	711	29	170	0.79	1,171	21.5	701
14	189	......	1,306	23.2	773	Feb. 1	188	......	1,296	23.6	776

TABLE 127.—*Basal metabolism of Ronald T. Veal—Squad A.*

Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.			Date.	Oxygen per minute.	Respiratory quotient.	Heat (computed) per 24 hours.		
			Total.	Per. kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).				Total.	Per kg. of body-weight.	Per sq. meter of body-surface (height-weight chart).
Normal.	*c.c.*		*cals.*	*cals.*	*cals.*	*Reduced.*	*c.c.*		*cals.*	*cals.*	*cals.*
1917.						1917.					
Sept. 29	247	......	1,699	25.8	944	Nov. 20	202	......	1,389	23.0	798
Oct. 2	227	0.78	1,560	23.7	867	22	195	......	1,341	22.2	771
4	227	......	1,553	23.6	863	23	194	......	1,334	22.1	767
Reduced.						24	179	0.79	1,234	20.5	709
Oct. 6	248	......	1,697	25.8	943	27	193	......	1,331	21.8	761
7	244	......	1,670	25.5	928	28	200	......	1,379	22.6	788
8	219	0.74	1,490	22.8	828	Dec. 3	209	......	1,441	23.6	823
10	232	......	1,588	24.3	882	4	203	......	1,400	23.4	809
11	234	......	1,601	24.5	889	5	191	0.79	1,318	22.0	762
12	231	......	1,581	24.2	878	7	194	......	1,341	22.7	780
15	217	0.78	1,493	23.0	834	10	248	......	1,715	29.1	997
16	213	......	1,457	22.4	814	11	198	......	1,369	22.8	791
17	224	......	1,534	23.6	857	12	186	0.80	1,286	21.4	743
19	229	......	1,567	24.1	875	14	203	......	1,400	23.4	809
21	218	0.72	1,493	23.3	839	16	194	......	1,338	22.7	778
23	215	......	1,471	23.0	826	18	186	0.78	1,279	21.5	739
25	218	......	1,493	23.3	839	19	193	......	1,331	22.4	769
27	206	0.74	1,402	21.9	788	1918.					
29	228	......	1.552	24.6	877	Jan. 8	200	0.79	1,380	23.1	798
30	227	......	1,545	24.5	873	9	211	......	1,459	24.6	848
Nov. 1	215	......	1,464	23.3	827	11	200	0.81	1,387	23.8	811
2	216	......	1,470	23.4	831	14	201	......	1,390	23.1	799
3	220	......	1,498	23.9	846	15	191	......	1,320	22.4	767
5	215	0.73	1,459	23.4	829	16	190	0.78	1,306	22.0	759
6	227	......	1,565	25.1	889	18	184	......	1,265	21.7	740
7	229	......	1,579	25.3	897	19	188	0.78	1,294	22.1	757
9	219	......	1,510	24.2	858	21	182	......	1,252	21.2	728
10	210	......	1,448	23.4	823	23	188	0.77	1,289	22.0	754
12	214	0.84	1,495	24.5	854	24	188	......	1,303	21.9	753
14	206	......	1,428	23.4	816	26	181	......	1,254	21.4	733
15	211	......	1,462	23.8	835	29	180	0.84	1,258	21.4	731
16	209	......	1,449	23.6	828	30	179	......	1,247	21.4	729
18	191	0.77	1,310	21.5	749	Feb. 1	178	0.81	1,234	21.1	722
19	196	......	1,348	22.1	770	2	189	......	1,310	22.3	762

TOTAL HEAT OUTPUT WITH LOW DIET, SQUAD A.

For a consideration of the total heat production of the squad at the beginning of the experiment, we have collected the data for all of the men in Squad A, except *Spe*, prior to diet restriction, and likewise the total heat output on the last three days of the experiment, and compared them in table 128. The values at the beginning of the experiment are usually the average of 3 to 5 days, but in the case of *Mon* 1 day is used. The total basal heat production at the beginning ranged from a minimum of 1,481 calories with *Bro* to a maximum of 1,858 calories with *Mon*. The average for the 11 men was 1,686 calories. The three measurements with *Kon* used for his normal average were

not obtained until the latter part of October, but they may properly be used here to indicate his metabolism prior to dietetic restriction. On the last 3 days of the experiment, the basal metabolism ranged from a minimum of 1,217 calories with *Pec* and *Tom* to a maximum of 1,590 calories with *Can*. The average for the 11 men was 1,367 calories. This represents a decrease of 319 calories or 19 per cent. Thus, by the restriction of diet the total basal metabolism of this squad was actually lowered 19 per cent.

Since the personnel of the squad changed somewhat during the experiment, inasmuch as *Kon* replaced *Fre* beginning with the fourth night in the large respiration chamber while *Spe* was not included in the group measurements after the sixth experiment, it would be illogical to compare the total heat output of the whole squad at the beginning and end of the experiment from measurements made with the group respiration chamber.

TABLE 128.—*Heat production at the beginning and end of period with reduced diet—Squad A, subjects post-absorptive and in lying position.*

Subject.	During normal diet.		During last 3 days with reduced diet.
	Days.	Average heat per 24 hours (computed).	Average heat per 24 hours (computed).
		cals.	*cals.*
Bro	4	1,481	1,271
Can	5	1,758	1,590
Kon	3	1,818	1,429
Gar	3	1,815	1,450
Gul	3	1,698	1,427
Mon	1	1,858	1,544
Moy	4	1,638	1,331
Pea	5	1,766	1,295
Pec	5	1,589	1,217
Tom	5	1,526	1,217
Vea	3	1,604	1,264
Average	4	1,686	1,367

HEAT OUTPUT PER KILOGRAM OF BODY-WEIGHT WITH LOW DIET, SQUAD A.

As a means of comparing the metabolism of different individuals or of the same individuals under different conditions the heat per kilogram of body-weight has been extensively used. The heat output computed on this basis is recorded in the gaseous metabolism tables for the individual subjects. In table 129 the heat production per kilogram of body-weight per 24 hours for the measurements nearest to October 1, November 24, and January 26 have been collected for the different subjects, October 1 representing the beginning of the experiment, November 24 a period of strict reduction, and January 26 approximately the end of the test. In obtaining these values, the method used has been to average the measurements on two days either side of the date here given, save in the case of October 1, for which all the values measured previous to the restriction in diet have been used in the average. Thus, for November 24 and January 26, the values for 5 days have, in general, been used. The values for *Bro* show a positive reduction in the heat production per kilogram of body-weight; with *Can* there was no appreciable change; with *Kon* there was a slight increase, with *Gar* and *Gul* a regular decrease; with *Mon* a

decrease about November 24 but no appreciable subsequent change about January 26; with *Moy* a continuous decrease throughout the entire period; with *Pea* a decided fall with practically constancy on November 24 and January 26; with *Pec* a continuous fall on the three dates; with *Spe* a considerable fall on November 24 but no record for January 26; with *Tom* a progressive decrease; with *Vea* a marked fall on November 24 but no subsequent change. The picture of the squad as a whole is shown by the average values, which are for October 1, 25.2 calories, for November 24, 23.1 calories, and for January 26, 22.3 calories. Here we have a clear picture of a continuous reduction in heat production per kilogram of body-weight from the beginning to the end of this long test, a picture fully confirmed by the data computed from the results of the experiments with the group chamber on the nights of September 29–30, November 24–25, and January 26–27.

TABLE 129.—*Heat per kilogram per 24 hours (computed from individual respiration experiments) at different diet levels—Squad A, subjects post-absorptive and in lying position.*

Subject.	During normal diet.[1]	At period of minimum weight.[1]	At end of period with reduced diet.[1]
	cals.	*cals.*	*cals.*
Bro	24.0	23.4	21.6
Can	22.0	22.4	22.0
Kon	....	22.4	23.1
Gar	25.5	23.1	22.2
Gul	25.4	24.2	21.7
Mon	27.0	25.6	25.3
Moy	25.8	23.7	23.3
Pea	25.5	22.0	21.4
Pec	24.7	21.9	20.5
Spe	27.3	23.0	....
Tom	25.6	23.1	22.5
Vea	24.4	21.8	21.6
Average	25.2	23.1	22.3
Squad average from expt. in group respiration chamber[2]	26.4	22.6	21.6

[1] See table 133 (footnotes) for explanation of period averages.
[2] Minimum during sleep, after standard supper (700 calories) at restaurant from 6 to 12 hours before the experiment. Computed from values in table 131, for experiments on Sept. 29–30, Nov. 24–25, and Jan. 26–27.

HEAT OUTPUT PER SQUARE METER OF BODY-SURFACE WITH LOW DIET, SQUAD A.

A second popular method for comparing different individuals and the same individual under different conditions is on the basis of the heat production per square meter of body-surface. Employing the measurements of body-surface obtained by the Du Bois linear formula, which have been verified both by the height-weight chart and by the photographic method (see p. 241), we have to deal here with true body-surfaces rather than with the erroneous values computed by the

formula of Meeh. The heat production per square meter of body-surface per 24 hours for each of the subjects has been computed for the days used in the previous comparison, *i. e.*, October 1, November 24, and January 26, and recorded in table 130. With the heat production per kilogram of body-weight there were a number of instances in which there was no decrease as the experiment progressed and occasionally even slight increases. When the values for heat production at these periods are compared on the basis of per square meter of body-surface, we find no increase except with *Kon*, whose heat production increased from 836 to 846 calories. In one case, *Vea*, the decrease on January 26 was small. The most marked decreases were noted between October 1 and November 24, as would be expected, for the latter date represents a period when the body-weight was practically at a minimum. Between November 24 and January 26 there was relatively little change in weight.

TABLE 130.—*Heat per square meter per 24 hours (computed from individual respiration experiments) at different diet levels—Squad A; subjects post-absorptive and in lying position.*

Subject.	During normal diet.[1]	At period of minimum weight.[1]	At end of period with reduced diet.[1]
	cals.	*cals.*	*cals.*
Bro	871	805	737
Can	893	844	834
Kon	....	836	846
Gar	992	844	808
Gul	974	876	783
Mon	1,027	914	897
Moy	926	807	796
Pea	987	794	769
Pec	908	775	716
Spe	990	788	....
Tom	882	766	740
Vea	891	759	740
Average	940	817	788
Squad average from expt. in group respiration chamber[2]	979	792	763

[1] See table 133 for explanation of period averages.

[2] Minimum during sleep, after standard supper (700 calories) at restaurant from 6 to 12 hours before the experiment. Computed from values in table 131, for experiments on Sept. 29–30, Nov. 24–25, and Jan. 26–27.

When a comparison is made with the data in table 113 (see p. 493), it is seen that the values in table 130 are not abnormal, although they show a somewhat wide range from a minimum of 871 with *Bro* to a maximum of 1,027 with *Mon*, a range of 156 calories. On November 24 we find all the values were perceptibly lowered, with no values above 914 calories, this maximum value being for *Mon*. The minimum value for this date, 759 calories, instead of being with *Bro* as on October

1, is found with *Vea*, the greatest difference in the figures being 155 calories, or practically the same as on October 1. On January 26 the range is from the maximum of 897 to a minimum of 716, a variation of 181 calories, which is somewhat greater than that noted on October 1. Since the whole level was lowered on the average 152 calories, it can be seen that this range of 181 calories on January 26 makes the actual percentage range larger than on the first day. Hence we may not infer that the restricted diet had a tendency to wipe out individual variations or deviations from the average. We note that while *Mon* shows the maximum heat output per square meter of body-surface per 24 hours for all three periods the minimum is represented on October 1 by *Bro*, on November 24 by *Vea*, and on January 26 by *Pec*. This implies, as was stated at the beginning in discussing the normality of these men, that the metabolism of *Mon* is distinctly on a higher level than that of the other men. It is also an interesting fact that the subject showing the next highest value on October 1 (*Gar*) is the third highest on November 24 and the fourth highest on January 26.

The average values for the entire squad show a continuous fall from 940 calories on October 1 to 817 calories on November 24 and 788 calories on January 26. The decrease between October 1 and January 26 is thus 16.2 per cent.

Attention is specially called to the fact that we have in the heat output per square meter of body-surface—a standard of measurement that supposedly levels all organisms from a mouse to an ox to the same physiological basis—a variation of 16 per cent with a group of 11 men between October 1 and January 26, a clear evidence of an absolute lowering of the heat per square meter of body-surface. Since the rectal temperature of these men remained essentially constant and, with one or two exceptions, the skin temperature was likewise constant, the significance of the body-surface law in this connection is hardly so great as one has been led to believe.

GROUP MEASUREMENT OF BASAL METABOLISM WITH LOW DIET, SQUAD A.

The successive metabolism measurements of Squad A in the group respiration chamber at intervals of approximately two weeks during the period of restricted diet have been recorded in table 131. Again emphasis must be laid upon the fact that the personnel of the squad through illness and other causes changed somewhat as the experiment continued. Hence the values for the total body-weight, total body-surface, and minimum carbon-dioxide production per hour can not be taken in a strictly comparative sense, and one should consider solely the values computed on the bases of heat production per kilogram per hour or per square meter per hour. These appear in the last two columns of the table.

The normal heat production, which was found on September 29–30 and has previously been recorded in table 114, is 1.10 calories per kilogram per hour and 40.8 calories per square meter per hour. The restricted diet began with breakfast on the morning of October 4. Approximately 10 days later (October 13–14), a second metabolism experiment showed a profound fall in the heat production to 1.02 calories per kilogram per hour and 37.6 calories per square meter per hour, a decrease of 7.3 per cent and 7.8 per cent, respectively. It so happens that these first two experiments represented values obtained with exactly the same personnel.

TABLE 131.—*Minimum metabolism during sleep as measured in group respiration chamber—Squad A.*

Date.	Total body-weight without clothing.	Total body-surface (height-weight chart).	Total carbon dioxide per hour.	Heat (computed) per hour.	
				Per kilogram.	Per sq. meter.
Normal diet:	*kg.*	*sq. meters.*	*gm.*	*cals.*	*cals.*
Sept. 29–30, 1917.	792	21.3	287	1.10	40.8
Reduced diet:					
Oct. 13–14, 1917.	777	21.1	249	1.02	37.6
Oct. 27–28, 1917.	[1]695	19.2	222	1.01	36.4
Nov. 10–11, 1917.	733	20.6	225	0.97	34.4
Nov. 24–25, 1917.	724	20.5	215	0.94	33.0
Dec. 8–9, 1917.	711	20.3	224	0.98	34.4
Dec. 19–20, 1917.	[1]654	18.7	208	0.96	33.7
Jan. 12–13, 1918.	[1]680	19.0	204	0.95	33.8
Jan. 26–27, 1918.	[1]665	18.8	192	0.90	31.8
Feb. 2–3, 1918.	[1]662	18.8	193	0.89	31.4

[1] Values represent 11 men only.

In the experiment on the night of October 27–28 but 11 men were in the squad. Hence there was a change in the total body-weight and body-surface and in the carbon-dioxide production. The heat production per kilogram of body-weight, however, is nearly identical with that obtained two weeks before, namely, 1.01 calories, but there was a decrease in the heat per square meter from 37.6 to 36.4 calories.

On November 10–11 the squad again consisted of 12 men and the heat production changed to 0.97 calorie per kilogram and 34.4 calories per square meter. These values remained essentially constant for the next four experiments, these being made on the nights of November 24–25, December 8–9, December 19–20, and January 12–13. It should be noted that beginning with December 19–20, the values are again for 11 men. On the night of January 26–27 another decided alteration was found in the heat production per kilogram of body-weight, which fell to 0.90 calorie, and in the heat production per square meter of body-surface, which fell to 31.8 calories. One week later, February 2–3, the

metabolism was again slightly lowered, minimum values for the entire experiment being obtained of 0.89 calorie for the heat production per kilogram of body-weight and 31.4 calories for the heat production per square meter of body-surface.

It is evident that as a result of the restricted diet, the heat production of the squad has been lowered both per kilogram of body-weight and per square meter of body-surface. If we take the normal values found on September 29–30 as a basis of comparison, these values being controlled not only by the morning average metabolism measurements with the respiratory-valve apparatus (see table 113) but likewise by a duplicate set obtained with the same apparatus with Squad B on October 7, we find that the alteration in the heat production per kilogram of body-weight was from 1.10 to 0.89 calories per kilogram of body-weight, a fall of 19 per cent. On the basis of per square meter of body-surface we find a change from 40.8 calories on the night of September 29–30—a value confirmed by those obtained with Squad B and likewise by the morning values secured with individual members of Squad A (see table 113)—to a value of 31.4 on the last night of the experiment, February 2–3, a decrease in metabolism per square meter of body-surface of 23 per cent.

From our experience in obtaining basal values with Squad B, however, it is not logical to assume that this decrease in the metabolism is due solely to the altered diet. With Squad B there was apparently a material seasonal fall in metabolism from October 7 to January 6, of 11 per cent per kilogram of body-weight, and 9 per cent per square meter of body-surface. (See discussion of table 114, page 497.) The decreases noted with Squad A are, however, so much greater than those found with Squad B that there is not the slightest doubt of a considerable alteration in the basal metabolism as a result of the diet restriction. The uncertain factor is the exact percentage to be ascribed to dietetic restriction and the exact percentage to be ascribed to the probable seasonal variation. Some hint as to the apportionment of these percentages may be obtained from an examination of the figures obtained with Squad B in the group respiration apparatus in the period of diet restriction. (See p. 523.)

COMPARISON OF INDIVIDUAL AND GROUP MEASUREMENTS OF BASAL METABOLISM WITH LOW DIET, SQUAD A.

Although the total heat production computed from the individual measurements of the gaseous metabolism in the morning experiments at Springfield with the respiratory-valve apparatus and the portable apparatus may not logically be compared with that computed from the results of the experiments with the group respiration chamber, since the personnel varied in the latter experiments, it is perfectly proper for us to compare the values for heat production on the two most commonly used bases, namely, per kilogram of body-weight and

per square meter of body-surface. Using the data given in tables 129 and 130 and comparing them with those found on the corresponding nights with the group respiration chamber, we may determine the general trend of the metabolism by two entirely different methods. Such a comparison is made in table 132.

TABLE 132.—*Comparison of measurements of metabolism with different diet levels and apparatus—Squad A.*

(Squad averages per 24 hours.)

Period.	Heat (computed) per kilogram of body-weight.		Heat (computed) per sq. meter of body-surface (height-weight chart).	
	Respiratory-valve app. and portable resp. app.[1]	Group respiration chamber.[2]	Respiratory-valve app. and portable resp. app.[1]	Group respiration chamber.[2]
	cals.	*cals.*	*cals.*	*cals.*
During normal diet	25.2[3]	26.4	940[3]	979
At period of minimum weight	23.1[3]	22.6	817[3]	792
At end of period with reduced diet	22.3[3]	21.6	788[3]	763
Decrease at end of reduced diet[4]	11.5%	18.2%	16.2%	22.1%

[1] Averages from determinations on individual subjects who were in post-absorptive condition, and lying awake.

[2] Computed from values on Sept. 29–30, Nov. 24–25, and Jan. 26–27, in table 131.

[3] See table 133 (footnotes) for explanation of period averages.

[4] $\dfrac{(\text{Normal values}-\text{Values at end of reduced diet})\times 100}{\text{Normal values}}$

Considering first the heat computed per kilogram of body-weight per 24 hours, we find that during normal diet, the value was slightly larger with the group chamber. At the period of minimum weight and at the end of the period with reduced diet the heat output was slightly lower with the group chamber. The percentage decrease from the beginning to the end of the experiment is also included in the a ble. With the individual measurements this was 11.5 per cent; witth the group chamber it was 18.2 per cent. While the agreement is by no means perfect between these two methods of measurement, both give clear indications of a decided change even in the heat output per kilogram per 24 hours. When one considers that the experimental procedures differed in almost every detail, the agreement is perhaps as close as one could expect.

On the basis of body-surface area the records show that during normal diet a somewhat larger value was obtained with the group chamber, but at the minimum weight and at the end of the reduced diet the conditions are reversed. In any event the agreement between the two series is strikingly close, considering the wide differences in the methods of experimentation. The actual percentage decrease noted with the individual respiration apparatus was 16.2 per cent and with the group chamber 22.1 per cent. Thus, with both types of respira-

tion apparatus, the evidence from this extensive series of experiments shows that the heat per kilogram of body-weight and heat per square meter of body-surface are greatly lowered, especially the latter.

A method of comparing the metabolism of these groups of individuals at different stages of their experiment which has a greater degree of scientific accuracy than the earlier methods previously discussed is to compare the basal metabolism as actually measured with that predicted by the Harris and Benedict formulæ for individuals of like age, height, weight, and sex. Such a comparison has already been made for the normal data in table 113 and discussed in that connection. A further comparison should be made between the predicted values and the results of the metabolism measurements obtained during the period of minimum weight and at the end of the diet period. This is given in table 133, which shows both the absolute and percentile differences as found in the individual measurements with the respiratory-valve and the portable respiration apparatus. The differences between the normal and predicted values are also included in this table for reference. *It is important to bear in mind that the predicted values are based upon a careful biometric analysis of the metabolism data obtained with a large number of individuals and are so adjusted as to give values with a reasonable degree of probability for individuals of the same height, weight, age, and sex.*[1]

Practically all of the men in Squad A show much greater differences between the predicted and found values at the period of minimum weight than at the beginning of the experiment when they were on normal diet. Thus we find that under normal conditions of diet 7 out of the 12 men considered show values greater than predicted. The average difference for the entire squad was 1.1 per cent above the predicted, the striking exception being *Mon*, with a plus difference of 12.5 per cent. At the period of minimum weight-level, namely, the latter part of November, all of the men, with the single exception of *Mon*, had values considerably below those predicted. *Mon's* metabolism was in excess of the predicted values by 1.5 per cent. The average computed value for the 12 men was 11.7 per cent below the predicted value. At the end of the reduced-diet period every man shows a computed heat production lower than the predicted value, although in the case of *Mon* this difference is insignificant, being only 2 calories, or 0.1 per cent. The average for the 11 men was 14.6 per cent below the predicted values. It is a matter of considerable importance that throughout the entire study *Mon* retained a consistent relationship in his total metabolism not only with the rest of the squad, but with the predicted values. When it is considered that we are comparing the total basal heat production as actually measured by the gaseous metabolism with that predicted for individuals of similar age, height, weight, and sex, as

[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919.

TABLE 133.—*Heat production at different diet levels as computed from respiration experiments and as predicted by Harris and Benedict—Squad A; subjects post-absorptive and in lying position.*

Subject.	During normal diet.[1]						
	(a) Age.	(b) Height.	(c) Body-weight without clothing.	Heat per 24 hours. (d) Predicted by Harris and Benedict.	Heat per 24 hours. (e) Computed from respiration experiments.[2]	Computed heat greater (+) or less (−) than predicted. (f) Total. (d−e)	Computed heat greater (+) or less (−) than predicted. (g) Per cent. $\left(\frac{f\times 100}{d}\right)$
	yrs.	*cm.*	*kg.*	*cals.*	*cals.*	*cals.*	
Bro....	26	167	61.8	1,576	1,481	− 95	− 6.0
Can....	26	177	79.8	1,874	1,758	−116	− 6.2
Kon[3]...	20	168	69.0	1,721	1,818	+ 97	+ 5.6
Gar....	22	171	71.3	1,754	1,815	+ 61	+ 3.5
Gul....	24	166	66.8	1,653	1,698	+ 45	+ 2.7
Mon...	32	171	68.8	1,652	1,858	+206	+12.5
Moy...	23	174	63.5	1,655	1,638	− 17	− 1.0
Pea....	21	169	69.3	1,723	1,766	+ 43	+ 2.5
Pec....	44	170	64.3	1,504	1,589	+ 85	+ 5.7
Spe....	19	171	63.5	1,667	1,733	+ 66	+ 4.0
Tom...	25	176	59.5	1,596	1,526	− 70	− 4.4
Vea....	22	175	65.8	1,698	1,604	− 94	− 5.5
Av ..	25	171	67.0	1,673	1,690	+ 18	+ 1.1

Subject.	At period of minimum weight.[4]						
	(h) Age.	(i) Height.	(j) Body-weight without clothing.	Heat per 24 hours. (k) Predicted by Harris and Benedict.	Heat per 24 hours. (l) Computed from respiration experiments.[2]	Computed heat greater (+) or less (−) than predicted. (m) Total. (k−l)	Computed heat greater (+) or less (−) than predicted. (n) Per cent. $\left(\frac{m\times 100}{k}\right)$
	yrs.	*cm.*	*kg.*	*cals.*	*cals.*	*cals.*	
Bro....	26	166	55.8	1,489	1,307	−182	−12.2
Can....	26	177	70.4	1,745	1,576	−169	− 9.7
Kon....	20	168	64.6	1,660	1,453	−207	−12.5
Gar....	22	172	63.8	1,656	1,477	−179	−10.8
Gul....	24	165	60.5	1,561	1,467	− 94	− 6.0
Mon...	32	171	61.4	1,550	1,574	+ 24	+ 1.5
Moy...	23	175	57.6	1,579	1,370	−209	−13.2
Pea....	21	169	62.1	1,624	1,362	−262	−16.1
Pec....	44	171	59.8	1,447	1,314	−133	− 9.2
Spe....	19	172	56.8	1,580	1,314	−266	−16.8
Tom...	25	176	56.0	1,549	1,292	−257	−16.6
Vea....	22	174	60.3	1,618	1,324	−294	−18.2
Av...	25	171	60.8	1,588	1,403	−186	−11.7

[1] The normal diet period includes experiments during Sept. 27 to Oct. 4, 1917, inclusive.
[2] See tables 115 to 127.
[3] The normal values for *Kon* were obtained on Oct. 27, 29, and 30.
[4] The period of minimum weight-level represents 5 experiments on or about Nov. 24.

TABLE 133.—*Heat production at different diet levels as computed from respiration experiments and as predicted by Harris and Benedict—Squad A; subjects post-absorptive and in lying position*—continued.

Subject.	At end of period with reduced diet.[1]						
	(o) Age.	(p) Height.	(q) Body-weight without clothing.	Heat per 24 hours.		Computed heat greater (+) or less (−) than predicted.	
				(r) Predicted by Harris and Benedict.	(s) Computed from respiration experiments.[2]	(t) Total. $(r-s)$	(u) Per cent. $\left(\frac{t\times 100}{r}\right)$
	yrs.	*cm*	*kg.*	*cals.*	*cals.*	*cals.*	
Bro....	26	167	54.9	1,481	1,188	−293	−19.8
Can....	26	178	70.6	1,752	1,561	−191	−10.9
Kon ...	20	168	62.5	1,631	1,450	−181	−11.1
Gar....	22	171	63.9	1,652	1,417	−235	−14.2
Gul....	25	166	60.7	1,563	1,314	−249	−15.9
Mon...	32	171	60.7	1,540	1,538	− 2	− 0.1
Moy...	23	174	58.0	1,579	1,350	−229	−14.5
Pea....	21	169	61.6	1,618	1,316	−302	−18.7
Pec....	44	171	58.8	1,433	1,203	−230	−16.1
Tom...	26	176	55.1	1,529	1,238	−291	−19.0
Vea....	22	174	58.6	1,594	1,269	−325	−20.4
Av...	26	171	60.5	1,579	1,349	−230	−14.6

[1] The period at the end of the reduced diet represents 5 experiments on or about Jan. 26, 1918.
[2] See tables 115 to 127.

derived from a series of prediction equations, it is obvious that the basis of comparison is much more fundamentally and firmly established than when the comparison is made on the basis of body-weight or body-surface.

It is seen, therefore, that not only on the basis of body-weight, as shown in earlier tables, as well as the questionable basis of body-surface, but also from these biometric prediction values, the basal metabolism was profoundly lowered with every member of Squad A. It is furthermore of significance that of the four men with pronounced negative values in column *g* on the normal diet, namely, *Bro, Can, Tom,* and *Vea*, three of them, *Bro*, *Tom*, and *Vea*, show absolutely greater negative values at the end of the experiment than all of the other subjects except *Pea*, thus suggesting a tendency to retain a relative position in the group so prominently indicated in the positive values noted with *Mon*.

GROUP MEASUREMENT OF BASAL METABOLISM WITH LOW DIET, SQUAD B.

Immediately following the night of January 6 inside the respiration chamber, Squad B was put upon a much restricted diet which averaged 1,375 net calories. The men came to Boston for experiments in the group respiration chamber on January 13, 19, and 27,

respectively. The minimum carbon-dioxide excretion per hour for the low-diet period, as found with the group chamber, also the computed heat per kilogram per hour and per square meter per hour are given in table 134. The normal values, previously recorded in table 114, are also included in this table. With the change to a much-restricted diet, there was a pronounced decrease in the carbon-dioxide production, a decrease in the heat per kilogram per hour amounting to but 1 per cent, and an appreciable decrease in the heat per square meter per hour. On January 20 the heat on both bases of computation was lower; on January 28 the minimum values were found.

TABLE 134.—*Minimum metabolism during sleep as measured in group respiration chamber—Squad B.*

Date.	Total body-weight without clothing.	Total body-surface (height-weight chart).	Carbon dioxide per hour.	Heat (computed) per hour.	
				Per kg.	Per sq. meter.
Normal diet:	*kg.*	*sq. m.*	*gm.*	*cals.*	*cals.*
Oct. 6–7, 1917.	805	21.8	292	1.10	40.5
Nov. 3–4, 1917.	814	21.9	295	1.10	40.7
Nov. 17–18, 1917.	815	21.9	292	1.08	40.3
Dec. 15–16, 1917.	818	21.9	287	1.06	39.6
Jan. 5–6, 1918.	815	21.8	265	0.98	36.8
Reduced diet:					
Jan. 13–14, 1918.	787	21.5	240	0.97	35.5
Jan. 19–20, 1918.	777	21.4	219	0.90	32.6
Jan. 27–28, 1918.	761	21.2	203	0.85	30.5

In examining this table one particularly regrets that normal values immediately subsequent to January 6 were not obtained before the restriction in diet was begun. The pronounced fall in the metabolism from December 16 to January 6, which, as previously stated, we are unable to explain, should have been further studied.[1] Although the fact that the heat per kilogram fell only slightly on January 14 might indicate that a further fall without dietetic restriction was hardly probable, nevertheless it represents a faulty point in the experimental plan. To begin a study of the effect of a superimposed factor upon a sliding base-line is experimentally bad. Furthermore, when so pronounced a fall in metabolism was shown on January 28, it is much to be regretted that the experiment could not have continued further. It will be remembered that Squad B was placed upon a restricted diet for the main purpose of obtaining data for comparison with some of the important findings noted in the earlier phases of the experiment with Squad A. Squad B, with a praiseworthy self-sacrificing spirit, volunteered to live upon this greatly restricted diet for a short period, so that the desired data might be obtained.

[1] See note on page 500.

In analyzing the figures obtained in these experiments, one is confronted by the difficulty of selecting the proper normal value for comparison. As previously stated, it is obvious that the only one that can be logically selected is that for January 6, since it was obtained immediately before the restriction in diet. Using this value, we find that the heat production per kilogram of body-weight per hour fell until on January 28 it was 13.3 per cent lower than it was on January 6. The heat production per square meter of body-surface per hour also fell until on January 28 it was 17.1 per cent lower than on January 6. With Squad A the computed heat values for the final experiment of February 2–3 gave values which indicated that there had been a decrease of 19 per cent in the heat production per kilogram of body-weight over the initial value found on September 29–30. For the heat production per square meter of body-surface it was 23 per cent. These findings with Squad B of 13.3 and 17.1 per cent, respectively, for the same factors are not quite so large, but the loss in body-weight and what is, we believe, of still more importance, the loss of body-nitrogen was by no means so great as it was with Squad A.

Using the normal values obtained with this squad in October, we may compute the total decrease in the heat output as shown by the value obtained on January 28. On this basis we find that there has been a decrease in the heat production from October 7 to January 28 (including both the seasonal variation and the variation due to the restricted diet) of 22.7 per cent, and on the basis of the heat per square meter of body-surface 24.7 per cent. These values actually exceed somewhat those found with Squad A. Had it not been for the series of observations on Squad B with uncontrolled diet on November 3–4, November 17–18, December 15–16, and January 5–6, these values would have been extremely difficult to interpret. The difficulty of applying an arbitrary base-line or an arbitrary so-called "standard" value to a series of experiments is apparent, even when group measurements are made.

The general picture of reduction, then, is approximately what would be expected from the loss in body-weight and the loss in nitrogen with Squad B as compared with Squad A. Both show pronounced alterations of the basal metabolism as the result of the restricted diet. The decrease is not only absolute but relative, being from 13 and 23 per cent lower per kilogram of body-weight and from 17 and 25 per cent per square meter of body-surface.

GENERAL CONSIDERATION OF THE EFFECT OF REDUCED DIET ON BASAL METABOLISM.

From the net calories required for maintenance at the lower weight level, we inferred that the caloric requirement had been reduced very considerably, *i. e.*, from a net intake of not far from 3,100 or even more calories to a net intake of 1,950 calories during the period of mainte-

nance at the low weight level. This involved not only the basal metabolism, but likewise the metabolism necessary for the general activity for the day. From the results of the metabolism experiments we find that this estimated loss in caloric requirement as based upon the caloric intake, using body-weight maintenance as an index, is reasonably substantiated. During the period of diet restriction, we find a lowering of body-weight amounting on the whole to not far from 10 to 11 per cent. We also find in periods of complete muscular repose, without extraneous muscular activity, there was a lowering of the heat production per kilogram of body-weight of not far from 20 per cent as computed from the group-chamber tests, making a total effect of caloric saving or a lowering of the total caloric maintenance of not far from 30 or more per cent. The differences found between the basal values in the group chamber (see table 132) and the values obtained with the respiration apparatus vitiate somewhat this generalization, and caution is necessary in these quantitative estimates.

EFFECT OF EXCESS DIET ON BASAL GASEOUS METABOLISM.

On several of the uncontrolled Sundays the subjects admittedly ate very large amounts of food.[1] Furthermore, as was shown in the discussion of the body-weight measurements (see p. 210), all of the subjects increased in weight perceptibly during the Christmas vacation and were on a rather free diet. The influence upon the basal metabolism of these excess feeding periods may be sharply noted in practically all instances on the return of the men to college in January 1918. In a number of instances the gaseous metabolism was also perceptibly increased on the Monday mornings following a Sunday with uncontrolled diet.

An examination of the values obtained in the morning respiration experiments with the respiratory-valve apparatus shows the effect of the excess food on the metabolism. The oxygen consumption may be used alone for this purpose, as the changes in the respiratory quotient are such as not to affect materially the heat production. Thus, on December 3, after the Thanksgiving recess, *Pea* had an average oxygen consumption in two periods of 209 c.c. per minute, as compared with an oxygen consumption of 192 c.c. on November 22, and of 195 c.c. on December 13. (See table 123, page 508.) With *Pec*, on October 29, after the uncontrolled Sunday of October 28, the

[1] The occasional Sundays when the diet was more or less uncontrolled we regarded as a necessary expedient. Some relaxation from the routine and the usual environment was almost a psychological requirement. The men looked forward with a good deal of pleasure to the occasions when they could eat food of their own choice. This made it more possible to keep the men contented and to extend the period of experimental observation. In this connection the introspection of *Moy* is pertinent. On May 21 he said: "It does seem in looking back over the experiment that we could have gotten on without the uncontrolled Sundays and the Thanksgiving recess, but these occasions were then greatly appreciated and we would have made an awful kick if they had been curtailed. You simply can not understand the matter. One's point of view is altogether different when he is in the experiment and when he is out of it."

oxygen consumption was 242 c.c., the highest value for the oxygen consumption obtained for this subject with the respiratory-valve apparatus in this research. Prior to this experiment the oxygen consumption was (October 24) 206 c.c. Before the reduction in diet, the one value obtained with *Pec* on the respiratory-valve apparatus (October 3) showed but 219 c.c.

The great increase in the oxygen consumption after the men returned to college in January is, however, of still more significance. The values for the oxygen consumption for the men in Squad A before and after the Christmas holidays have been collected and tabulated in table 135, in which it is seen that in every instance there was a very considerable increase in the oxygen consumption after the Christmas recess. The maximum increase was found with *Gar* of 35 c.c. per minute; the minimum was with *Kon* of 10 c.c. per minute.

TABLE 135.—*Effect of overeating upon the oxygen consumption of Squad A.*

Subject.	Oxygen consumption per minute.		
	Last observed before Christmas.	First observed after Christmas holidays.	Initial value before reduced diet.
	c.c.	*c.c.*	*c.c.*
Bro	176	195	215
Can	227	251	266
Kon	232	242	265
Gar	202	237	271
Gul	193	215	249
Mon	210	225	273
Moy	196	229	209
Pea	197	209	253
Pec	182	203	219
Tom	169	198	204
Vea	186	200	227

It is also of interest to compare these increments in the oxygen-consumption level after the return from the Christmas vacation with the initial oxygen values. The latter are given in the last column of table 135. With one subject, *Moy*, the oxygen consumption on the return to college is actually higher than it was at the beginning of the year, being 229 c.c. after Christmas as against the initial value of 209 c.c. With *Tom* the difference was only 6 c.c. per minute. With all others the post-Christmas value was at least 15 c.c. less than the initial oxygen measurement. It is clear, therefore, from this table that the period of free eating during the Christmas holidays, possibly in conjunction with other factors, such as freedom from college activities and anxieties, contributed materially towards increasing the oxygen consumption. The gaseous metabolism curves show, however, that the oxygen consumption rapidly decreased after the rise following the Christmas period.

The stimulus to the metabolic activity as a result of these periods of excess feeding was thus greatly increased. It is regrettable that a control of these subjects was not possible during this period, or, in the absence of strict dietetic control, at least an exact knowledge obtained of the total output of nitrogen in the urine.

GASEOUS METABOLISM WITH STANDING POSITION.

In obtaining the basal values for a series of treadmill experiments at the Nutrition Laboratory, individual measurements were made with the men in both squads standing prior to walking, *i. e.*, on the mornings of January 6 and 28 with Squad B and on the morning of February 3 with Squad A. With Squad B the values determined on the morning of January 6 were prior to the diet restriction; those found on the morning of January 28 were after 3 weeks of low diet. With Squad A the measurements were made on the last morning of the experiment. This experimental material, while collected in a somewhat unsatisfactory manner, since only one experiment of two periods was made with the portable respiration apparatus for each subject, supplies interesting evidence regarding two important points. The data regarding the basal metabolism were measured in these standing experiments under exactly the same experimental conditions as the minimum values obtained with the group respiration chamber in that they were secured with the subject in the post-absorptive condition and without muscular activity, other than that required for standing, and, with Squad B, both before and after diet restriction. On the other hand, the values for the standing position would be expected to be distinctly higher than those measured with the group respiration chamber, since in the latter apparatus the subjects were lying in deep sleep.

GASEOUS METABOLISM WITH STANDING POSITION, SQUAD B.

With Squad B a comparison may be made of the values obtained with the subject in the standing position before and after diet reduction; such a comparison is made in table 136. These values give us not only the average value for the whole squad, but likewise enable us to study the changes in the metabolism of individual members of the squad. Since the heat production per minute is used in subsequent tables for the calculation of the metabolism during the treadmill experiments, it is retained in table 136, but the values of special interest to us in this discussion are those computed for the heat production per kilogram per hour for January 6 and for January 28. The decrease in the heat production on this basis as a result of the reduction in diet, also the percentage of decrease, are recorded in the last two columns of the table, the data obtained on January 6, with normal diet, being used as the basal values. As the personnel of the squad changed somewhat between these two dates, and *How* found difficulty in breathing through the mouthpiece of the apparatus (see page 535), the values for only 10 men are available for comparison.

From the data in table 136 we find that after 3 weeks of low diet each man in Squad B showed a decrease in the heat output per kilogram per hour which ranged from a minimum of 0.11 calorie with *Sne* to a maximum of 0.29 calorie with *Tho*, with an average of 0.17 calorie

for the whole squad. On the percentage basis these 10 men showed on the average a decrease of 14.1 per cent, the minimum being 9.5 per cent with *Sne* and the maximum 22.1 per cent with *Tho*. The percentage decrease for practically all of the other men was not far from the average of 14.1 per cent. We may conclude, therefore, from these two series of experiments that a lowering of the metabolism per kilo-

TABLE 136.—*Post-absorptive metabolism during standing preliminary to walking on treadmill—Squad B.*

Subject.	Normal diet, Jan. 6, 1918.			Reduced diet (20 days), Jan. 28, 1918.			Decrease in heat per kg. per hour.	
	(a) Body-weight without clothing.	Heat (computed). (b) Per minute.	Heat (computed). (c) Per kg. per hour.	(d) Body-weight without clothing.	Heat (computed). (e) Per minute.	Heat (computed). (f) Per kg. per hour.	(g) Total (c−f).	(h) Per cent $\left(\frac{g \times 100}{c}\right)$
	kg.	*cals.*	*cals.*	*kg.*	*cals.*	*cals.*	*cals.*	
Fis..........	76.3	1.46	1.15	71.7	1.22	1.02	0.13	11.3
Har..........	63.7	1.36	1.28	59.1	1.05	1.07	.21	16.4
Ham..........	74.8	1.49	1.20	69.9	1.19	1.02	.18	15.0
Kim..........	61.9	1.23	1.19	59.9	1.05	1.05	.14	11.8
Sch..........	68.6	1.31	1.15	63.8	1.10	1.03	.12	10.4
Liv..........	63.6	1.28	1.21	58.6	1.00	1.02	.19	15.7
Sne..........	72.9	1.41	1.16	67.7	1.19	1.05	.11	9.5
Tho..........	63.2	1.38	1.31	59.3	1.01	1.02	.29	22.1
Van..........	69.8	1.35	1.16	64.8	1.09	1.01	.15	12.9
Wil..........	59.8	1.36	1.36	56.9	1.09	1.15	.21	15.4
Average...	67.5	1.36	1.22	63.2	1.10	1.04	0.17	14.1

gram due to the restriction in diet is shown not only when Squad B was measured as a group, but when the men were measured individually. In the discussion of table 134 (see p. 523) it was brought out that when the values for January 6 were used as a base-line the low diet produced a decrease in the metabolism of the group as a whole of 13.3 per cent with the subjects lying quietly asleep in the group chamber. This value is almost identical with the reduction shown in table 136 of 14.1 per cent for 10 members of the squad standing quietly. This fact has a double interest, first, as a general confirmation of the lowering of the metabolism due to the decrease in the amount of food, and second, as an indication that with a low diet not only is the heat output during complete muscular repose reduced about 13 or 14 per cent, but likewise the heat output with the subject standing with a slightly higher metabolic level shows a similar percentage reduction.

The metabolism for the standing and lying positions can not be compared with each man in Squad B to note the effect of change in position, as no individual measurements of the metabolism were made with these subjects in the lying position, and comparisons with other

individuals in the lying position would have no significance in this connection. A group comparison can be made, however. If we compare the values found in table 134 with those given in table 136, we find that the basal metabolism with the subjects lying quietly on the night of January 6 was, for Squad B, 0.98 calorie per kilogram per hour. The average value for the standing position as determined with the portable respiration apparatus on the morning of January 6 was 1.22 calories per kilogram per hour, an increment of approximately 24 per cent of standing over lying in complete muscular repose. The basal value found with the whole group on January 28 when the subjects were lying quietly in the large respiration chamber was 0.85 calorie. To compare with this we have the average value of 1.04 calorie on the morning of January 28. Under these conditions the increase in metabolism due to standing may be taken as 22 per cent. Thus, although there has been an actual decrease in the metabolism as a result of the restriction in diet, not only with the subjects asleep and quiet, but likewise when they were standing and quiet, the influence of the standing upon the basal metabolism is practically identical under the contrasting conditions of diet, namely, an increase in the heat production per kilogram of body-weight due to standing of 22 to 24 per cent.

GASEOUS METABOLISM WITH STANDING POSITION, SQUAD A.

With Squad A no standing experiments were made with the portable respiration apparatus prior to the restriction in diet, the only experiment being that on the last day of the low-diet research (February 3). We are thus unable to determine the effect of the reduction in diet upon the metabolism in the standing position. We may, however, observe the effect of a change in position when the subject is at this low level of metabolism. To compare with the standing values obtained on February 3 we have basal data secured during experiments with one or the other of the respiration apparatus in Springfield one or two days prior to the date of the standing experiment, when the subjects were lying quietly and in the post-absorptive condition. The comparison between these values is made in table 137.

The average basal lying value for these men as shown in table 137 is 0.96 calorie per kilogram of body-weight per hour. The average standing value is 1.07 calories. With each individual in Squad A an increment is noted in the standing values for February 3 over those obtained with the subject lying quietly on the respiration apparatus in Springfield. These increments are recorded in the next to the last column of table 137, and in the last column are given the percentage increases for standing over lying. The percentage increases range from 2 per cent with *Kon* to a maximum of 19.8 per cent with *Moy*. The average for all subjects is 11.4 per cent; in other words, the standing position increased the metabolism 11.4 per cent above that obtained in the lying position.

TABLE 137.—*Comparison of energy metabolism in lying and standing positions—Squad A; subjects post-absorptive, at end of period of reduced diet.*

Subject.	Lying (respiratory-valve or portable respiration apparatus).						Standing (portable respiration apparatus).			Increase in heat, standing over lying.	
	Date.	Body-weight without clothing.	Oxygen per minute.	Respiratory quotient.	Heat (computed).		Body-weight without clothing (Feb. 3, 1918).	Heat (computed).		Total increase.	P. ct. increase.
					Per hour.	Per kg. per hour.		Per minute.	Per kg. per hour.		
	1918.	*kg.*	*c. c.*		*cals.*	*cals.*	*kg.*	*cals.*	*cals.*	*cals.*	
Bro	Feb. 2	55.0	186	[1]0.80	53.6	0.97	54.4	1.00	1.10	0.13	13.4
Can	...do	70.5	230	0.80	66.3	.94	69.3	1.27	1.10	.16	17.0
Kon	...do	62.5	213	[1]0.80	61.4	.98	61.5	1.03	1.00	.02	2.0
Gar	Feb. 1	65.0	223	[1]0.80	64.2	.99	63.0	1.22	1.16	.17	17.2
Gul	Jan. 31	60.5	200	0.78	57.3	.95	61.0	1.01	.99	.04	4.2
Mon	Feb. 1	60.8	219	[1]0.80	63.1	1.04	60.6	1.16	1.15	.11	10.6
Moy	Feb. 2	59.0	197	[1]0.80	56.7	.96	57.8	1.11	1.15	.19	19.8
Pea	Feb. 1	61.0	185	0.79	53.2	.87	61.3	.97	.95	.08	9.2
Pec	Feb. 2	59.0	185	0.79	53.2	.90	59.1	.97	.99	.09	10.0
Tom	Feb. 1	54.8	188	[1]0.80	54.2	.99	55.1	1.00	1.09	.10	10.1
Vea	Feb. 2	58.8	189	[1]0.80	54.4	.93	58.5	1.01	1.04	.11	11.8
Average						.96			1.07	.11	11.4

[1] Respiratory quotient of 0.80 assumed for the experiments with the portable respiration apparatus.

The minimum heat production of Squad A found with the group respiration chamber the night before (the night of February 2–3) was 0.89 calorie per kilogram per hour instead of the average of 0.96 calorie shown in table 137 for the metabolism in the lying position. If we use this 0.89 calorie as a basal value for comparison with the average value of 1.07 calories obtained in the standing position on February 3, we find an increase over the minimum value during the night of 0.18 calorie. On this basis the increment over lying is 20.2 per cent, which compares favorably with the increase due to standing of 22 per cent found with Squad B by a similar method of comparison. Both values are, however, measurably higher than the average increase for Squad A of 11.4 per cent found in table 137, in which the basal value used was that obtained in the lying experiments in Springfield made with respiration apparatus similar to that used for the standing experiments.

CONCLUSIONS REGARDING STANDING EXPERIMENTS.

The standing experiments therefore show conclusively that with the reduced diet there was a decrease in the metabolism per kilogram of body-weight, even when the subjects were standing quietly, which amounted to about 14 per cent with the men in Squad B. This decrease was approximately that found with the same squad lying quietly inside the group respiration chamber.

The standing experiments further show that with Squad B the reduction in the metabolism due to the restriction in diet was experienced by each man in the squad, with a reasonably constant percentage decrease per kilogram of body-weight of about 14 per cent. In other words, there was no marked predisposition on the part of any of the men either for or against this reduction, the decreases ranging from 9.5 to 22.1 per cent. In consideration of the fact that these values were all obtained in experiments made rather rapidly and but few in number, the agreement is somewhat striking, to say the least. The general picture for the squad is perfectly clear, namely, a pronounced reduction due to the diet, even in the standing position, with a fair degree of uniformity for the individual members of the squad.

A comparison of the standing experiments with the results obtained with the subjects in the lying position gives an increment for the standing position over the lying position of 22 to 24 per cent with Squad B and of 20.2 per cent with Squad A, when the basal value used is that obtained with the group respiration chamber. When the average value for Squad A found in the individual measurements with the respiration apparatus in Springfield is taken for the basal lying value, the increment is reduced nearly one-half, *i. e.*, to about 11 per cent.

RESPIRATORY QUOTIENT.

With such changes in the dietetic intake as were made in these experiments, changes not only in the total katabolism but likewise in the character of the katabolism would reasonably be expected; hence an analysis of our data for the respiratory exchange should be made with a view to studying the character of the katabolism. The respiratory quotient, that is, the ratio between the carbon dioxide excreted and the oxygen consumed, is the best index we have of the character of the katabolism. A high respiratory quotient indicates that a large proportion of carbohydrate is being burned in the body and a low quotient a large proportion of fat. Since the portable respiration apparatus is designed to give an accurate measure of the oxygen consumption only, our study of the respiratory quotients of these subjects must depend upon the quotients found in the experiments with the respiratory-valve apparatus; these, however, are not numerous. The respiratory quotients obtained are given in the gaseous-metabolism tables for the individual subjects. (See tables 115 to 127.)

The respiratory quotient showing the normal basal value prior to the reduction in diet is best obtained from the average respiratory quotients in table 113. This gives an average quotient for the whole squad of 0.80. This normal value is in accord with the value obtained by Benedict, Emmes, Roth, and Smith with the 89 men, and by Carpenter, Emmes, and Hendry with the 17 Harvard Medical School students. An inspection of the respiratory quotients in the several gaseous metabolism tables reveals a tendency for the quotients to be on the whole somewhat lower with the restricted diet, as values below 0.80 appear more frequently than those above. Individual instances of high respiratory quotients are, however, frequently noted in connection with the high metabolism found on the days following the periods of uncontrolled diet on Sundays and during the Thanksgiving and Christmas recesses. Typical illustrations of this are the respiratory quotients for *Mon* on December 3 and 10, obtained on the Mondays following Sundays with unrestricted diet. The respiratory quotient on December 3 was 0.92 and on December 10 it was 0.89. Likewise on Monday, January 14 (following another unrestricted Sunday diet) the respiratory quotient was 0.88 as compared with 0.75 on January 10 with controlled diet. On the same Monday (January 14) *Gul's* respiratory quotient was 0.87 as compared with 0.79 on January 9. With *Pea* on the two Mondays, December 3 and 10, the respiratory quotients were 0.86 and 0.93, respectively. A general inspection of the data shows that these high quotients are characteristic of the Monday mornings following the uncontrolled diets of Sunday or after the holidays. This would imply a storage of carbohydrates as a result of the uncontrolled eating. Aside from these high quotients resulting from the uncontrolled diet, the low-diet quotients show a general uni-

formity at about 0.79. Certain abnormally low respiratory quotients also appear in our values, but none lower than 0.73 were used in the calculation of the heat production. Those below 0.73 are as follows: *Bro*, September 29, 0.70; *Can*, October 10, 0.72; *Gul*, January 18, 0.72; *Mon*, November 3, 0.68; *Pec*, January 7, 0.72; and *Vea*, October 21, 0.72. No simple explanation for these low values is at hand.

From the foregoing it is seen that the respiratory quotients here given have a general interest in that they show a tendency toward a lowering in the katabolism of carbohydrate and probably of the glycogen storage. After the unrestricted days there was invariably a noticeable tendency for an increase in the respiratory quotient, indicating a higher consumption of carbohydrate on these days. The respiratory quotients in no case approach a level indicating a carbohydrate-free diet or a state of glycogen depletion bordering upon incipient acidosis.

A practical use which was made of the respiratory quotient in this research was to compute from it the calorific value of the carbon-dioxide production in the experiments with the group respiration chamber, for, as is well known, the calorific value of carbon dioxide varies considerably with the respiratory quotient. The quotients obtained on the days nearest to the experiments in the group respiration chamber were used for determining the calorific value of the carbon dioxide produced.

GASEOUS METABOLISM DURING WALKING.

The experimental procedures have made it possible to analyze the basal metabolism under different conditions of nutritional level with the normal and with the low diet. Furthermore, as was seen in a preceding section, the metabolism with both normal and reduced diet was studied for the standing position, this representing a somewhat greater expenditure of energy than that for the lying position, and the influence of the restricted diet was found to be of practically the same magnitude as that affecting the lying metabolism. The treadmill experiments make it possible to study the influence of the lower nutritional level upon a moderately active form of muscular exercise. While in the lying experiments there is no voluntary muscular effort and in the standing experiments the muscular effort is only slight, walking approximates, to a certain extent, a great deal of the activity incidental to the ordinary life of most individuals not engaged in severe manual labor. The walking experiments, therefore, are of particular value in determining the influence of the low nutritional state upon the probable metabolism during periods of time other than quiescent, *i. e.*, periods with a moderate amount of activity.

In the walking experiments here discussed it was possible to measure quantitatively a condition of metabolic activity involving an increase in metabolism of over 200 per cent above the basal standing metabo-

lism. The treadmill experiments may be looked upon, therefore, from two standpoints, first, as to the capacity of the organism to carry out a simple physical operation, such as that of walking a given distance, and second, as to the efficiency with which the operation may be done. Knowing from the earlier researches of Durig and his associates that when weight is added in the form of a load on the back, the energy required for the transportation of this material is, up to a certain limit, essentially constant per kilogram of body-weight, we could assume *a priori* that when these men had lost a certain amount of weight they would be able to walk a given distance with a lower metabolism. It should be borne in mind, however, that the experiments of Durig deal with a basal metabolism of a constant intensity and with an organism living at a normal nutritional level. Although it has been shown in the foregoing sections that the basal metabolism was very greatly lowered as a result of the restricted diet, it is not logical to assume, without supporting experimental evidence, that the walking would be accomplished necessarily with essentially the same degree or a less expenditure of energy.

In addition to considering the capacity of the organism to transport itself a given distance, one may very properly consider whether the energy required to transport 1 kg. of body-weight 1 meter in a horizontal direction has been materially affected by the change in diet. With a relatively large number of individuals, at least, the average figures have shown approximately uniform constancy for this factor. This is more of an abstract physiological phase of the problem and of somewhat less practical importance. In the following analysis of our walking experiments, therefore, we will first consider the capacity of the organism as a whole to transport itself or to walk a given distance, in the belief that walking makes up a not inconsiderable amount of the activity of each individual during the day, and likewise, as has been pointed out earlier, walking is one of the most practiced and commonest muscular performances of mankind.

The technique described in an earlier section, employing the treadmill and the closed chamber with gas analyses for both carbon-dioxide increment and oxygen deficit, was utilized to determine the total heat production during the process of walking. It has been the custom of investigators, however, to recognize that a certain proportion of this heat is required for the ordinary maintenance activity. In the calculation of the heat required for walking, this maintenance energy is usually deducted from the total heat during the walking period. The time available for these experiments was not sufficient for us to determine both the total heat production of walking and the heat of maintenance in the treadmill chamber. Use was therefore made of experiments with the portable apparatus, in which the subject was in the standing position, it being the consensus of opinion of physiologists

that the basal metabolism standing is one of the best base-lines for maintenance activity for deduction from the total gaseous metabolism during walking.

The observations of the gaseous metabolism during walking included two series of experiments with Squad B on January 6 and 28, and one series of experiments with Squad A on February 3. The first series with Squad B was made when the men were on full diet, the second when they had been on a much reduced diet for 20 days. The single series of experiments with Squad A was made at the end of the research, when the men had been on low diet with some intermissions for about 4 months. These walking experiments were preceded in all cases by basal standing experiments.

WALKING EXPERIMENTS WITH NORMAL DIET, SQUAD B.

The series of experiments on January 6 was made specially to serve as a base-line for subsequent experiments after diet restriction. Unfortunately, on January 6 an accident to the Sondén gas-analysis apparatus after walking experiments had been made with 5 subjects rendered it impossible to determine the oxygen consumption and to compute the respiratory quotient for the other 7 men on that date. The average quotient obtained with the 5 subjects was therefore used for these 7 men and the heat was calculated from this average figure. Fortunately, the carbon-dioxide measurements in all cases are satisfactory. *How*, on both January 6 and 28, had difficulty in using the mouthpiece in the standing experiments; consequently the oxygen consumption for this subject in the standing position was not obtained directly, but was calculated from his body-weight, and the average oxygen consumption per kilogram of body-weight of the other members of the squad on these dates. The results of the basal standing experiments have been discussed in a previous section (see p. 527), and find use in the subsequent calculations.

The method of calculation for a typical walking experiment has been given in the technique section (see p. 136). It is unnecessary here to present all the protocols, but it is important to note that the temperature of the air inside the chamber in all series of experiments, with both Squad A and Squad B, was within a narrow range—with Squad B on January 6 ranging from 21.37° C. to 23.45° C. On January 28, with the same squad, the range was from 19.90° C. to 21.67° C. With Squad A, on February 3, the temperatures were slightly higher, the range being from 19.59° C. to 22.86° C. In individual experiments the difference in temperature readings at the beginning and the end rarely exceeded 0.5° C.

The moisture accumulated slowly as the experiment progressed, but at no time became excessive. Expressed in percentages, the increase in humidity was usually from 3 to 10 per cent. The average

humidity for the experiments on January 6 with Squad B was not far from 33 per cent and on January 28 approximately 30 per cent; on February 3, with Squad A, it was perceptibly higher, and more nearly 50 per cent.

Obviously in experiments lasting but 20 to 24 minutes, barometric changes are physiologically insignificant.

The more important data from the experiments on January 6 with Squad B have been brought together in table 138. It is specially to be noted that the body-weight used in all of these treadmill experiments is not that appearing in all other tables of this monograph, but includes the weight with clothing, electrodes, and pneumograph, for we are particularly interested here in the actual weight transported in the process of walking. These men had their last meal at 5 p. m. the evening previous, so *Van*, who was the first subject, had been 12 hours without food and was therefore in the post-absorptive condition. This subject was wakened at 4 a. m. and began his standing experiment at 4^h25^m a. m.; as the squad had retired at 11 p. m., he had had only 5 hours of sleep that night; but *Tho's* walking experiment was not made until 12^h25^m noon; it was therefore $19\frac{1}{2}$ hours since his last meal, but he had had a full night's rest. These differences in the hours of rest and intervening time between the previous meal and the experiment could not be avoided in these individual measurements; though undesirable, they were probably without significant influence.

From table 138 it is seen that the rate of walking is practically uniform at 69.4 meters per minute, even the grossest variation being only 0.5 meter. This is evidence of the careful control of the treadmill speed. The total heat per minute is recorded in column *h*. As was the case with the standing metabolism, the total heat output is in general agreement with the weight of the subject, the heaviest men having usually the largest heat output. The exceptions to this were no more frequent nor larger than might be expected in general. Although the speed of the treadmill was adjusted to that for moderate walking, it seems best to discuss the total distance walked more in terms of an average day's walking performance for these men. It was found that, in general, Squad A showed pedometer records of not far from 6.5 miles per day.[1] Consequently we have used for both squads the round figure of 10 km. to represent the total distance walked daily. The total heat required in walking 10 km. has been computed for Squad B and recorded in the last column of table 138 (column *l*). The average value of 626 calories as the heat produced while walking 10 km. corresponds approximately to one-seventh of the daily net energy intake of the men in Squad B at this time. The value for the average heat required to walk 10 km. (626 calories) may be assumed to be a basal unit which will be referred to when the experiments made upon the subjects at the lower nutritional level are considered.

[1] See p. 645.

TABLE 138.—*Increase in the heat output during walking in treadmill chamber and the computed total heat required in walking 10 kilometers—Squad B normal, January 6, 1918.*

(a) Subject.	(b) Weight with clothes, electrodes, etc.	(c) Distance per minute.	(d) Horizontal kilogram-meters per minute ($b \times c$).	(e) Carbon dioxide per minute.	(f) Oxygen per minute.	(g) Respiratory quotient.	Heat output per minute (computed). (h) Total.	(i) During standing.	Increase over standing. (j) Total. (h-i)	(k) Per horizontal kilogrammeter $\left((j \div d) \times 1000\right)$	(l) Total heat required in walking 10 km.[1] $\left(\frac{h \times 10{,}000}{c}\right)$
	kg.	*meters.*		*c. c.*	*c. c.*		*cals.*	*cals.*	*cals.*	*gm. cals.*	*cals.*
Fis	78.9	68.9	5,436	718	....	0.80[2]	4.31	1.46	2.85	0.524	626
Har	66.0	69.3	4,574	679	....	.80[2]	4.07	1.36	2.71	.592	589
How	74.0	69.3	5,128	846	1,036	.82	5.00	1.46[3]	3.54	.690	719
Ham	77.9	69.6	5,422	824	....	.80[2]	4.94	1.49	3.45	.636	711
Kim	64.8	69.9	4,526	766	....	.80[2]	4.60	1.23	3.37	.745[4]	658
McM	71.5	69.2	4,948	766	....	.80[2]	4.60	1.37	3.23	.653	665
Sch	70.8	69.4	4,910	709	874	.81	4.21	1.31	2.90	.591	607
Liv	66.0	69.6	4,594	645	....	.80[2]	3.87	1.28	2.59	.564	556
Sne	75.5	69.1	5,217	626	828	.76	3.91	1.41	2.50	.479	566
Tho	66.1	69.9	4,620	757	....	.80[2]	4.54	1.38	3.16	.684	650
Van	72.5	69.4	5,032	691	842	.82	4.06	1.35	2.71	.539	586
Wil	62.0	69.6	4,315	669	838	.80	4.02	1.36	2.66	.617	578
Av	70.5	69.4	4,894	725	884	.80[2]	4.35	1.37	2.97	.597	626
Av[5]	70.4	69.5	4,889	721	884	....	4.32	1.37	2.95	.592	622

[1] Equivalent to 4.2 km. (2.6 miles) per hour, at rate of 70 meters per minute. [2] Average of quotients for five subjects. [3] Computed; see page 535. [4] Omitted in average. [5] Omitting McM.

It should be emphasized here that this value represents the *total* heat output of an individual in walking this distance.

We have, furthermore, to consider specifically the increase in the heat output for walking under these conditions. This is shown in column *j*, in which the heat for standing as measured in the standing experiments is deducted from the total heat. The heat output shown in this column represents the increase in the caloric output per minute for individuals walking a definite distance, for all the subjects walked the same distance on the treadmill. In other words, it represents a difference in calorific value per minute ranging from 2.50 calories with *Sne* to 3.54 calories with *How*. These differences in heat output are, it is seen, independent of the body-weight of these two individuals, for both men had essentially the same body-weight, or 74 kg., as compared with 75.5 kg. From an inspection of the values for body-weight and for total heat increase over standing, it is difficult to note any relationship.

A comparison of the values for total heat output per minute (column *h*) or even for the increase in heat over standing (column *j*) does not give a definite idea of the efficiency of the man, for owing to differences in body-weight (in these experiments distances remain constant) varying amounts of work were performed. It is therefore desirable, in so far as possible, to secure the caloric data with regard to the performance of unit amounts of work, *i. e.*, the heat required to transport 1 kg. 1 meter in a horizontal direction. We have accordingly (as is customary in reporting experiments of this kind) divided the total heat output above standing by the total horizontal kilogrammeters, namely, the body-weight times the distance walked (column *d*). By this we find the coefficient for the heat output per horizontal kilogrammeter (column *k*).

From these values it is seen that *Sne* was able to move 1 kg. of body-weight 1 meter with the least output of energy (0.479 gram-calorie), while *Kim* expended the most at 0.745 gram-calorie. This extreme value of 0.745 gram-calorie found for *Kim* is open to suspicion, for such a heat output is not approached by any of the other subjects during these tests or by any of the normal men shown in table 139. Excluding the value of 0.745 gram-calorie, the average heat output per horizontal kilogrammeter is 0.597 gram-calorie for the remaining 11 men of the squad which is used for future comparisons.

This average figure may also be compared with the values found with 8 other subjects[1] studied in this Laboratory which are given in table 139. There is considerable diversity in this table in the rate of walking, and it has not been possible to find exact data for comparison. The apparatus used was the universal respiration apparatus with mouthpiece and nose-clip, so that differences in technique between the two series may be expected to influence the results in some degree. These

[1] Detailed data to appear in a later publication.

figures show an average cost per horizontal kilogrammeter of 0.535 gram-calorie. Benedict and Murschhauser[1] report values obtained for 2 normal subjects (their Subject I and Subject II) of 0.507 and 0.493 gram-calorie, and also give an average figure of 0.550 gram-calorie computed from a summary of the work of Zuntz, Durig, Brezina, and others.[2] The average value of 0.597 gram-calorie for the 11 men of Squad B is somewhat higher than the values found by the other methods, though the variations are not on the whole any greater. Since such striking prominence is given in table 138 to the individual coefficient per horizontal kilogrammeter, it must be emphasized that these represent determinations upon one subject for one period in the

TABLE 139.—*Average metabolism of normal men for horizontal walking.*

Subject.	No. of experiments.	Weight with clothes.	Distance per minute.	Heat (computed).	Increase over standing.	Heat per horizontal kilogrammeter.	Range of values in series.
		kg.	*meters.*	*cals.*	*cals.*	*gm.-cals.*	*gm.-cals.*
E. D. B..	13	59.5	69.8	2.98	1.90	0.458	0.422—0.508
E. L. F...	9	72.7	51.4	3.39	2.10	.562	.536— .655
J. H. G...	9	69.6	54.9	3.37	2.04	.533	.509— .564
T. H. H..	9	57.2	67.7	3.30	2.19	.568	.533— .609
W. K....	7	51.7	67.5	2.83	1.69	.487	.443— .559
T. J. L...	4	62.2	59.6	3.09	1.76	.475	.453— .501
H. R. R..	3	73.8	67.5	4.52	3.12	.627	.603— .668
H. M. S..	3	65.8	52.8	3.10	1.98	.568	.558— .585
Average	......	64.1	61.4	3.32	2.10	.535	.507— .581

day and hence should not be directly compared to the average values given in table 139, which represent in all cases average values of from 3 to 13 periods. Hence attention is called to the differences in values found in table 139 for the series of normal individuals. It is there seen that in the entire series the lowest average found was 0.458 and the highest 0.627. The lowest average, 0.458, is 0.021 lower than the lowest found with any member of Squad B, *i. e.*, 0.479. The highest average for the normal individuals was 0.627 which is exceeded in table 138 by members of Squad B in five instances, *How*, *Ham*, *Kim*, *McM*, and *Tho*. The average for the entire squad, 0.597, is clearly somewhat higher than not only the average found with the normals, namely, 0.535, but likewise the three sets of averages reported in earlier publications. The values found for Squad B in table 138 are to be used primarily for comparative purposes with another set determined on the same individuals by exactly the same technique after 20 days of reduced diet. It is to be remembered that we have here with this apparatus

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, pp. 77 and 82.
[2] *Ibid.*, p. 28.

but 12 individual experiments with 12 different men. The fact that their average value is somewhat higher than that found by another technique with 8 other subjects, and which represented a large number of series, is not to be given undue prominence.

WALKING EXPERIMENTS WITH REDUCED DIET, SQUAD B.

Two days after the experiments on January 6 were made with Squad B the reduction in diet previously discussed was begun and continued for 20 days. On January 28, the last day of restricted diet, a second series of tests was made. These duplicated in every respect those of January 6, with the exception that *McM* had been obliged to leave the squad and *Lon* had returned.

The metabolism of the men as measured while standing, preliminary to walking, appears in table 136. From tables 138 and 140, we find that the average heat production per minute of the 12 subjects fell from 1.37 calories on January 6 to 1.10 calories on January 28, or a decrease in the heat output from the body of 19.7 per cent. The averages are unaffected by including the values found with *McM* and *Lon*.

A summary of the gaseous metabolism and computed heat output for the walking experiments of January 28 is given in table 140. Here, also, the average rate of walking remained constant in all experiments, again attesting to the uniformity in action of the mill. The respiratory quotients, except that for *Wil*, which is relatively high, are fairly uniform and are of the usual value. The total heat output bears a reasonable relationship to the body-weight of the subject. Special attention is called to the values for the total heat required for walking 10 km., *i. e.*, the average day's walking performance. The average for the entire squad is 533 calories. These values in the last column may be compared to the corresponding values on January 6 for normal diet. The total heat increase above standing is of special significance, but attention must also be called to the heat requirement for transporting 1 kg. 1 meter (column *k*). Here the values range from 0.493 with *Tho* to a maximum of 0.652 with *Har*. The average value is 0.562. The range in values in this series of experiments is very much less than that in the earlier series, in which it will be recalled that the values ranged from 0.479 to 0.745. A comparison of the average values may be made best in connection with the comparison of all the several factors.

COMPARISON OF THE GASEOUS METABOLISM OF SQUAD B ON RESTRICTED DIET WITH THAT ON NORMAL DIET.

Having considered the details of the metabolism experiments as recorded at the end of the 20 days of restricted diet, we are in a position to compare all the physiological activities and metabolic conditions with the normal period prior to dietetic restriction and to note the influence, if any, of the diet restriction. For this purpose we have

TABLE 140.—*Increase in the heat output during walking in treadmill chamber and the computed total heat required in walking 10 km.—Squad B, 20 days restricted diet, January 28, 1918.*

(a) Subject.	(b) Weight with clothes electrodes, etc.	(c) Distance per minute.	(d) Horizontal kg.meters per minute. (b×c).	(e) Carbon dioxide per minute.	(f) Oxygen per minute.	(g) Respiratory quotient.
	kg.	meters.		c.c.	c.c.	
Fis	75.3	69.7	5,245	713	952	0.75
Har	62.5	69.3	4,431	640	824	.78
How	68.8	69.7	4,792	680	852	.80
Ham	73.3	69.4	5,084	609	835	.73
Kim	63.3	69.8	4,415	571	742	.77
Lon	67.0	69.4	4,650	584	721	.81
Sch	66.3	70.3	4,657	581	747	.78
Liv	61.5	69.4	4,268	570	744	.77
Sne	71.5	69.7	4,984	640	836	.77
Tho	62.5	69.8	4,363	527	660	.80
Van	68.0	69.7	4,740	581	765	.76
Wil	59.3	69.8	4,136	568	657	.87
Average	66.6	69.7	4,641	605	778	.78
Average[3]	66.5	69.7	4,647	607	783	.78

(a) Subject.	Heat output per minute (computed).				(l) Total heat required in walking 10 km.[1] $\left(\frac{h \times 10,000}{c}\right)$
	(h) Total.	(i) During standing.	Increase over standing.		
			(j) Total. $(h-i)$.	(k) Per horizontal kg. meter. $(j \div d) \times 1000$	
	cals.	cals.	cals.	gm.-cals.	cals.
Fis	4.51	1.22	3.29	0.627	647
Har	3.94	1.05	2.89	.652	569
How	4.08	1.14[2]	2.94	.614	585
Ham	3.93	1.19	2.74	.539	566
Kim	3.53	1.05	2.48	.562	506
Lon	3.47	1.01	2.46	.529	500
Sch	3.56	1.10	2.46	.528	506
Liv	3.54	1.00	2.54	.596	510
Sne	3.96	1.19	2.77	.556	568
Tho	3.16	1.01	2.15	.493	453
Van	3.63	1.09	2.54	.536	521
Wil	3.21	1.09	2.12	.512	460
Average	3.71	1.10	2.61	.562	533
Average[3]	3.73	1.10	2.63	.565	536

[1] Equivalent to 4.2 km. (2.6 miles) per hour, at rate of 70 meters per minute.
[2] Computed; see page 535. [3] Omitting Lon.

drawn in table 141 an abstract of the important gaseous and heat measurements for all the members of Squad B at the two nutritional levels.

This table is primarily a comparison table and indicates, in the first place, the pronounced fall in weight which has been discussed in a previous section. All the men lost in weight, the smallest loss being

that with *Kim*, amounting to but 2.3 per cent of his initial body-weight, and the largest with *How*, with 7.0 per cent of his body-weight. The uniformity of the mill is attested by the indication of no appreciable changes in distance walked per minute. The total heat output during standing and the increase above standing show a material falling-off during the 20-day test. As pointed out in a previous section, the

TABLE 141.—*Comparison of the metabolism during walking in treadmill chamber of Squad B normal on January 6, and on January 28 after 20 days restriction in diet, with per cent change from normal.*

Subject.	Condition.	Weight.	Distance per minute.	Heat output per minute during standing.	Increase in heat output per minute over standing.	Heat output per horizontal kilogrammeter.	Total heat required in walking 10 km.
		kg.	*meters.*	*cals.*	*cals.*	*gm.-cals.*	*cals.*
Fis......	Normal...	78.9	68.9	1.46	2.85	0.524	626
	20 days..	75.3	69.7	1.22	3.29	.627	647
	Per cent..	−4.6	+1.2	−16.4	+15.4	+19.7	+3.4
Har......	Normal...	66.0	69.3	1.36	2.71	.592	589
	20 days...	62.5	69.3	1.05	2.89	.652	569
	Per cent..	−5.3	0.0	−22.8	+6.6	+10.1	−3.4
How.....	Normal...	74.0	69.3	1.46[1]	3.54	.690	719
	20 days...	68.8	69.7	1.14[1]	2.94	.614	585
	Per cent..	−7.0	+0.6	−21.9	−16.9	−11.0	−18.6
Ham.....	Normal...	77.9	69.6	1.49	3.45	.636	711
	20 days...	73.3	69.4	1.19	2.74	.539	566
	Per cent..	−5.9	−0.3	−20.1	−20.6	−15.3	−20.4
Kim.....	Normal...	64.8	69.9	1.23	3.37	.745[2]	658
	20 days...	63.3	69.8	1.05	2.48	.562	506
	Per cent..	−2.3	−0.1	−14.6	−26.4	−24.6	−23.1
Liv......	Normal...	66.0	69.6	1.28	2.59	.564	556
	20 days...	61.5	69.4	1.00	2.54	.596	510
	Per cent..	−6.8	−0.3	−21.9	− 1.9	+5.7	−8.3
Sch......	Normal...	70.8	69.4	1.31	2.90	.591	607
	20 days...	66.3	70.3	1.10	2.46	.528	506
	Per cent..	−6.4	+1.3	−16.0	−15.2	−10.7	−16.6
Sne......	Normal...	75.5	69.1	1.41	2.50	.479	566
	20 days...	71.5	69.7	1.19	2.77	.556	568
	Per cent..	−5.3	+0.9	−15.6	+10.8	+16.1	+0.4
Tho......	Normal...	66.1	69.9	1.38	3.16	.684	650
	20 days...	62.5	69.8	1.01	2.15	.493	453
	Per cent..	−5.4	−0.1	−26.8	−32.0	−27.9	−30.3
Van......	Normal...	72.5	69.4	1.35	2.71	.539	586
	20 days...	68.0	69.7	1.09	2.54	.536	521
	Per cent..	−6.2	+0.4	−19.3	−6.3	− 0.6	−11.1
Wil......	Normal...	62.0	69.6	1.36	2.66	.617	578
	20 days...	59.3	69.8	1.09	2.12	.512	460
	Per cent..	−4.4	+0.3	−19.9	−20.3	−17.0	−20.4
McM....	Normal...	71.5	69.2	1.37	3.23	.653	665
Lon......	20 days...	67.0	69.4	1.01	2.46	.529	500
Av. normal (omitting McM)......		70.4	69.5	1.37	2.95	0.592	622
Av. 20 day (omitting Lon).......		66.5	69.7	1.10	2.62	.565	535

[1] Computed; see page 535. [2] Not included in average.

decrease in heat output when standing was found with all subjects. The heat output above standing, *i. e.*, that specifically involved in the work of walking, was decreased in all but 3 cases. A striking exception is the case of *Fis*, with whom there was an increase of 15.4 per cent; there were also increases with *Har* and *Sne*. The averages show a decrease from 2.95 calories on January 6 to 2.62 calories on January 28.

Of special significance is the total heat required for walking 10 km. This was almost always largely decreased, the two exceptions being the increase for *Fis* of 3.4 per cent and the insignificant change of 0.4 per cent with *Sne*. On the average these men as individual organisms were able to walk 10 km. at a very considerably reduced expenditure of energy. At the end of 20 days the average individual required for walking 10 km. a total of 535 calories. This is a decrease on the average of 87 calories in the total heat required in walking this distance, or approximately 14 per cent, and represents a real saving for the transportation of the individual over a given distance.

Owing to the unusual physiological interest in the efficiency of the human organism as a machine, the values for the heat per horizontal kilogrammeter have especial significance. It is seen that this value is in some instances increased and in others decreased. The most prominent increases are those of 19.7 per cent with *Fis* and 16.1 per cent with *Sne*. The most prominent decreases are those of 24.6 per cent with *Kim*, 27.9 per cent with *Tho*, 17.0 per cent with *Wil*, and 15.3 with *Ham*. It is extremely unfortunate that it is necessary to take the general picture from a series of observations that vary as widely as do these. Nevertheless, it seems reasonably clear that the average value found prior to reduction on the normal day of 0.592 when compared to the average reduction found on January 28 of 0.565 represents a real, though relatively slight, decrease. In brief, of the 11 subjects tested on the two days, 4 show an increase, 1 shows practically no change and 6 show a decrease in this factor.

From the average heat output with the subject standing and the heat output over and above standing shown in table 141, it is possible to compute approximately the distribution of the heat saving between the standing and walking requirements. It is seen that the decrease in the heat output for standing for the two dates was 0.27 calorie and the decrease in the heat output required on walking over and above that required for standing was 0.33 calorie. Of the total saving, then, of 0.60 calorie, that on the standing constituted 45 per cent and that on the walking 55 per cent. These figures have some interest, though the individual variations are wide. Six of the 11 subjects, however, showed that about 30 per cent of the saving was on the standing metabolism and 70 per cent on the walking metabolism.

While the reduction in body-weight in part explains the pronounced reduction of 14 per cent in the energy required for walking 10 km.,

it is of very great importance to note that not only were these men able to walk 10 km. at a very much less expenditure of energy than prior to their diet restriction, but that per unit of work done the figures for the horizontal kilogrammeter constants distinctly imply an increase in efficiency.

WALKING EXPERIMENTS WITH SQUAD A.

Since only one series of experiments was made with Squad A and that on the last day of diet restriction, the basal values for this group of subjects prior to diet restriction are lacking. We must accordingly rely for controls first upon the series with Squad B on full diet, and second, so far as necessary, upon the series of observations made upon normals in the Nutrition Laboratory.

Such a comparison may reasonably be made, for, in the first place, with Squads A and B we are dealing with similar groups of men; second, the average nude weight of the individuals in the two squads differed but 1 kg. from each other. The men were of reasonably uniform age, and represent homogeneous material drawn from the college body. In other words, the average body-weight and general condition of Squads A and B were essentially the same prior to the reduction in diet, so that any change in metabolism of Squad A as a whole may not illogically be compared to the normal values for Squad B. Attention should, however, be called to the fact that Squad B did exhibit apparently a seasonal variation, as pointed out in an earlier section. We are hereby assuming that the same seasonal variation would have been shown by Squad A; in other words, that the basal metabolism of Squad A would be as low as that of Squad B.

The preliminary standing tests with Squad A have been previously discussed; the data which are used for the computation of the increments are drawn from table 137.

The metabolism measurements and the computations for the heat during walking have been summarized for all the members of Squad A in table 142. The uniformity in distance walked is here again shown.

The respiratory quotients, with three exceptions, *Gar*, *Gul*, and *Tom*, are not far from those to be expected from men on the character of the diet employed. It seems quite clear that the quotients over 0.90 are not correct. It may or may not be significant that two of these high values, 0.89 and 0.93, are associated with the lowest horizontal kilogrammeter factors. We see no reason, however, for excluding these values from the averages. The total heat (column *h*) represents reasonably close conformity with the body-weight. The total heat required in walking 10 km., as recorded in the last column, shows the average for this squad is 484 calories. The actual amount of work performed is given in column *d*, from which the heat output on the unit basis of a horizontal kilogrammeter is obtained (column *k*). These

TABLE 142.—*Increase in the heat output during walking in treadmill chamber and the computed total heat required in walking 10 km.—Squad A, 120 days restricted diet, February 3, 1918.*

(a) Subject.	(b) Weight with clothes, electrodes, etc.	(c) Distance per minute.	(d) Horizontal kg.-meters per minute. (b×c).	(e) Carbon dioxide per minute.	(f) Oxygen per minute.	(g) Respiratory quotient.
	kg.	*meters.*		*c.c.*	*c.c.*	
Bro	58.0	69.7	4,043	527	659	0.80
Can	72.5	69.6	5,046	653	789	.83
Kon	64.8	69.3	4,487	580	736	.79
Gar	66.8	69.7	4,653	596	673	.89
Gul	64.0	69.6	4,454	614	665	.92
Mon	63.8	70.0	4,463	574	745	.77
Moy	60.3	70.0	4,218	557	668	.83
Pea	64.8	69.2	4,481	573	744	.77
Pec	62.5	69.6	4,350	558	676	.83
Tom	58.0	69.7	4,043	529	569	.93
Vea	61.8	69.4	4,286	608	743	.82
Average	63.4	69.6	4,410	579	697	.84

(a) Subject.	Heat output per minute (computed). (h) Total.	(i) During standing.	Increase over standing. (j) Total. $(h-i)$.	(k) Per horizontal kg.-meter. $\left((j \div d) \times 1000\right)$	(l) Total heat required in walking 10 km.[1] $\left(\frac{h \times 10{,}000}{c}\right)$
	cals.	*cals.*	*cals.*	*gm.-cals.*	*cals.*
Bro	3.16	1.00	2.16	0.534	453
Can	3.81	1.27	2.54	.503	547
Kon	3.52	1.03	2.49	.555	508
Gar	3.31	1.22	2.09	.449	475
Gul	3.30	1.01	2.29	.514	474
Mon	3.55	1.16	2.39	.536	507
Moy	3.23	1.11	2.12	.503	461
Pea	3.55	0.97	2.58	.576	513
Pec	3.25	0.97	2.30	.529	467
Tom	2.82	1.00	1.82	.450	405
Vea	3.58	1.01	2.57	.600	516
Average	3.37	1.07	2.30	.522	484

[1] Equivalent to 4.2 km. (2.6 miles) per hour, at rate of 70 meters per minute.

constants when compared to the normal values in table 139, are seen to be remarkably uniform, varying only from 0.449 with *Gar* to 0.600 with *Vea*.

COMPARISON OF RESULTS OF WALKING EXPERIMENTS WITH SQUADS A AND B.

The average values found with Squad A and the average normal for Squad B can best be summarized in connection with a review of the comparisons with Squad B before and after reduced diet. These comparisons are made in table 143.

For the reasons given previously, we believe the values for Squad B normal may be properly assumed to represent the values for Squad A normal, and the computations are thus made in table 143. The distance walked remained the same in all tests. The body-weight in all tests decreased. The total heat output required to walk 10 km. decreased with the 12 men of Squad B 14.8 per cent. With the 11 men of Squad A, whose period of reduced diet was much longer with a much greater loss of body-weight, it decreased 22.7 per cent. This decrease represents in both cases a pronounced fall in the total energy requirement for the transportation of the individual over a given distance.

TABLE 143.—*Comparison of the metabolism of Squads A and B on reduced diet with Squad B normal for a basis.*

Groups of subjects and conditions compared.	Average weight with clothes, electrodes, etc.	Distance walked per minute.	Horizontal kilogram-meters.	Heat output per horizontal kilogram-meter.	Change from Squad B normal.	Total heat required in walking 10 km.	Change from Squad B normal.
	kg.	*meters.*		*cals.*	*p. ct.*	*cals.*	*p. ct.*
Squad B, normal..	70.5	69.4	4,894	0.597[1]	....	626	....
Squad B, 20 days..	66.6	69.7	4,641	.562	6.0	533	14.8
Squad A, 120 days[1]	63.4	69.6	4,410	.522	12.6	484	22.7

[1] Average of 11 subjects.

It thus appears that the demonstrated decrease in the metabolism of these individuals, when resting quietly, and when standing quietly, is also noted in walking, and that the organism can walk at much less expenditure of energy with low diet. This of itself is an extremely important practical point. From earlier experiments of Durig and his school, who have studied the effect of superimposed loads, one may reasonably assume that with the reduced diet the individual can not only walk a given distance, but can transport a load equivalent to the loss in body-weight at no greater expenditure of energy than was noted prior to the diet reduction. In this sense there would be a distinct economic gain, for each kilogram of body-weight lost may now be transported in the form of effective external load and the total energy requirement or expenditure not exceed that prior to restriction.

When one considers the organism as a system of levers and attachments for performing muscular work, and that during the process of weight reduction these levers have decreased in weight with, in consequence, a lessened demand for energy for their movement, it can be seen that the lighter the member, other things being equal, the more effective the mechanical operation.

Of special significance, however, is a consideration of the values for the heat output per horizontal kilogrammeter, *i. e.*, for the same

unit of work. As previously pointed out, with Squad B there was a slight decrease in this factor, indicating an increased efficiency. A change in this factor is of such great physiological importance that it is only with considerable reserve that one should draw deductions from it. Remembering that the normal data with Squad B on January 6 had a wide variation and that Squad A on reduced diet have no normal values obtained with them directly for use in such comparison, and that the normal values for Squad B must therefore be employed, it may be considered unjustifiable to draw a definite conclusion that the subjects walked at a greater efficiency on a reduced diet than under normal conditions. Nevertheless, the figure of 6 per cent with Squad B is substantiated, at least to a reasonable extent, by the figure of 12.6 per cent with Squad A. It is thus probable that there is a distinct increase in efficiency, even when considering the activity from the standpoint of per unit of work accomplished.

While a larger group of subjects would be desirable, it is believed that the number of men studied is sufficiently large to average most of the individual variations. The three sets of experiments were made in exact duplicates and the conditions of the series were similar. The results from the three series may therefore be taken as contributory to the whole picture. In considering these results it should be remembered that in this test the influence of practice was reduced to an almost negligible quantity. Every muscle employed in treadmill walking was employed a hundred fold over in the daily routine of each man. The rate of walking was purposely made moderate to eliminate the question of excessive work, and the periods were brief enough to eliminate the question of fatigue.

While we believe that the conclusions regarding these experiments show unquestionably an actual saving in energy for the transportation of the body of the individual over a stated distance and distinctly imply, also, that each unit of work is accomplished with a somewhat higher degree of efficiency, the important relationship between this type of work and muscular activities in general should here be emphasized. Walking is a practiced effort. The experiments were planned for tests with moderate exercise of a well-established and practiced character. But in consideration of the fact that not only is there an absolute total saving in energy, but a probability of a slight saving per unit of work, we have every reason to believe that similar increases in efficiency, both total and relative, would be shown with other forms of exercise including, indeed, industrial operations, if the influence of fatigue and excessive work were eliminated. On these two latter points these experiments do not give and were not planned to give any evidence. Whether the men would show equal efficiency in prolonged walking or heavy-grade walking on a reduced diet as on a normal diet is a question for further study. But the conclusion seems clear to us

that these results show that the men of both Squads A and B—Squad A at a maintenance period and Squad B while undergoing a rigid diet reduction—walked with a saving in total energy expended and with a somewhat greater efficiency per unit of work than did Squad B on a normal diet.

NUMBER AND LENGTH OF STEPS IN WALKING EXPERIMENTS.

In connection with the walking experiments the uniformity in the number of steps and in length of step while walking a given distance was studied by means of photographic records. (See p. 129). These data are in table 144. From the distance walked, length of period, and the number of steps as computed from the photographic records, the average number of steps taken per minute, length of step, and total number of steps per 100 meters are found. It is evident that if the mill is maintained at a definite speed, these last three values are functions of each other, and if the man shortens his step he must take more of them to cover a given distance.

By comparing the results of Squad B on January 6 and 28, it is seen that *Fis* took longer strides and fewer steps per 100 meters on January 28 than on January 6, and that *Sne* had the same length of stride and number of steps per 100 meters on the two days. The record for *How* for January 28 is not available for comparison.

With these exceptions, the other members of the squad all shortened their stride and increased the number of steps per 100 meters on January 28. That this change in the length of stride is characteristic throughout the whole period, and that there is no marked alteration as the walking progressed, is shown by the figures given in the same table giving the length per step at the sixth, twelfth, and twenty-fourth minutes, as calculated from the photographic records and the distance traveled during that portion of the experiment when the record was made.

On January 6 *Har* showed an apparent change in stride following the sixth minute and on January 28 *Sch* apparently shortened his stride. Aside from these variations, there appear no marked changes except that the one-minute observations of January 6 indicate more irregularities than the other periods; this is probably due to the regulating of the mill, which, as previously stated, generally took a minute before adjustment to the desired speed of 70 meters per minute was secured. For this reason the figures in this column have not been included in the averages for this day.

As normal data for Squad A were not obtained, the data for this squad observed with low diet can only be compared as an average of 11 men with the average of the 11 men of Squad B. Such a comparison is of less significance than the comparison of the individual changes for each man, for one or two men with long legs might alter

TABLE 144.—*Record of the steps per minute, length of stride, and number of steps per 100 meters for Squads A and B on January 6, 28, and February 3, together with the length of step as computed from the photographic records on the sixth, twelfth, and twenty-fourth minutes of walking.*

SQUAD B, NORMAL, JAN. 6, 1918.

Subject.	Total distance walked.	Steps taken as computed from photographic records.	Average no. of steps per minute.	Average length of steps.	Steps per 100 meters.	Length of step at end of— 1 min.	6 min.	12 min.	24 min.
	meters.			*cm.*		*cm.*	*cm.*	*cm.*	*cm.*
Fis.....	1,377	1,872	94	74	135	71.2	73.9	74.0	75.3
Har.....	1,386	1,824	91	76	132	77.1	79.3	74.2	73.5
How....	1,385	1,980	99	70	143	73.3	69.5	70.5	67.5
Ham....	1,392	1,854	93	75	133	71.9	75.8	78.6	74.3
Kim....	1,397	1,880	94	74	135	73.8	75.8	73.6	74.4
Sch.....	1,388	1,948	97	71	141	66.7	73.7	72.5	73.1
Liv......	1,392	2,114	106	66	151	66.1	65.5	66.7	64.8
Sne.....	1,382	1,946	97	71	141	70.0	70.7	71.3	72.3
Tho.....	1,398	1,856	93	75	133	75.9	75.3	75.9	74.6
Van.....	1,388	1,845	92	75	133	....	....	74.9	75.5
Wil.....	1,392	2,112	106	66	151	64.6	66.2	68.2	64.8
Avg...	1,389	1,932	97	72	139	71.1	72.6	72.8	71.8

SQUAD B, 20 DAYS, JAN. 28, 1918.

Subject.	Total distance walked.	Steps taken as computed from photographic records.	Average no. of steps per minute.	Average length of steps.	Steps per 100 meters.	1 min.	6 min.	12 min.	24 min.
	meters.			*cm.*			*cm.*	*cm.*	*m.*
Fis.....	1,394	1,824	91	76	132	....	75.6	77.0	76.8
Har.....	1,386	1,822	92	75	133	....	....	75.4 ..	....
Ham....	1,388	1,940	97	72	139	....	73.6	73.1 ..	....
Kim....	1,396	2,038	102	69	145	....	68.2	68.5	68.8
Sch.....	1,406	2,016	101	70	143	....	74.8	70.1	68.1
Liv.....	1,388	2,204	110	63	159	....	63.1	63.9	61.8
Sne.....	1,394	1,974	99	71	141	....	71.2	69.8	70.9
Tho.....	1,395	1,970	99	71	141	....	70.0	......	71.8
Van.....	1,394	1,944	97	72	139	....	....	......	71.9
Wil.....	1,396	2,210	111	63	159	....	63.0	64.2	62.1
Avg...	1,394	1,994	100	70	143	....	69.9	70.3	69.0

SQUAD A, 120 DAYS, FEB. 3, 1918.

Subject.	Total distance walked.	Steps taken as computed from photographic records.	Average no. of steps per minute.	Average length of steps.	Steps per 100 meters.	1 min.	6 min.	12 min.	24 min.
	meters.			*cm.*			*cm.*	*cm.*	*cm.*
Bro.....	1,394	2,006	100	70	143	....	68.4	......	70.7
									22′ 24′
Can.....	1,392	1,974	99	71	142	....	69.6	70.5	70.9 71.0
Gar.....	1,394	1,962	98	71	141	....	71.1	71.0	71.2
							4′ 6′	8′	20′
Gul.....	1,392	2,004	100	69	144	....	68.2 69.4	68.8	70.9
Kon....	1,386	2,160	108	64	156	....	63.1	62.9	66.5
Mon....	1,400	1,986	99	71	142	....	69.6	71.5	....
Moy....	1,399	1,876	94	75	134	....	73.5	74.4	75.8
Pea.....	1,384	2,190	109	63	158	....	61.5	63.3	64.9
Pec.....	1,391	2,186	109	64	157	....	63.6	63.9	63.2
Tom....	1,394	2,000	100	70	144	....	69.3	70.1	69.7
Vea.....	1,387	1,934	97	72	139	....	72.0	71.5	73.2
Avg...	1,392	2,025	101	69	146	....	68.3	68.8	69.7

the average of the groups considerably. However, the two measurements W and R employed in measuring the body-surface area of the men on January 27 and February 2 (see pp. 234-237), show that the difference in length of leg was slight, the length for Squad B averaging 89.7 cm. and that for Squad A 88.7 cm. The averages of the two groups are accordingly compared in table 145 which shows the decrease in the average length of stride and the increase in the number of steps per minute and per meter for the three tests.

TABLE 145.—*Comparison of average of distance walked, steps taken, and length of step of Squads B, normal, B 20-day, and A 120-day during walking in the treadmill chamber.*

Groups of subjects and conditions compared.	Distance walked.	Steps taken.	Av. steps per min.	Av. length per step.	Steps per 100 meters.
	km.			*cm.*	
Squad B, normal.....	1,389	1,932	97	72	139
Squad B, 20 days.....	1,394	1,994	100	70	143
Squad A, 120 days....	1,392	2,025	101	69	146

How close may be the connection between these results and the lowering of the heat output per horizontal kilogrammeter is uncertain. That it may have some bearing is reasonable to suppose. Not a little of the actual work of forward progression consists of lifting the body on the toes as one leg is swung past the other. Benedict and Murschhauser[1] published some measurements on this toe-lift and found that their Subject I, who weighed 73.1 kg., in walking at a rate of 75.9 meters per minute, lifted the body on the average 3.78 meters per minute, which was equivalent to 0.65 large calorie, or 23 per cent of the increase over the standing metabolism.

Jendrássik[2] has shown that in horizontal walking the body is held longer in equilibrium on one foot, while in grade walking the equilibrium is maintained longer on both feet. It is possible that in these experiments, with a lowered nutritional level, the body endeavored to spare itself the effort of maintaining equilibrium on one foot and excessive toe-lift, and found in a shorter and quicker step a means to this end. It is, at least, an interesting coincidence that *Fis* and *Sne*, who showed no decrease in length of stride nor increase in number of steps per 100 meters on January 28 over January 6, both showed an increase in the heat output per horizontal kilogrammeter. The cases of *Har* and *Liv*, who also showed increased cost per horizontal kilogrammeter, are in contrast to the behavior of these two.

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 80.
[2] Jendrássik, Arch. f. Phys., 1904, Supp. Band, p. 287.

RESULTS OF NEURO-MUSCULAR AND PSYCHOLOGICAL MEASUREMENTS.

The laboratory measurements used in the psychological phase of this research on the effects of short rations have been described in an earlier chapter. (See p. 137.) It will suffice here to note that careful instructions preceded each measurement. At the first two sessions with each squad the instructions were fairly detailed. Later it was only necessary to emphasize the chief points, each of which could be called to the subject's mind by a word or two from the one taking the measurement. In the group work the instructions were always detailed. It is a pleasure to record the serious attitude, the remarkable cooperation, and general fine spirit of the men who served as subjects in both Squads A and B. They readily consented to do whatever was asked of them. There was no tendency to beg to be excused, to shirk, or, on the other hand, to frustrate experimental plans. In the matter of willingness and attitude the men who served left little to be desired.

Attention has been called (p. 491) to the conditions which made it imperative to begin the reduction in diet almost immediately after the opening of the college year. These circumstances of course rendered it impossible to secure an adequate base-line in the psychological measurements with Squad A. The men came to the Laboratory only once (September 29) before the reduction in diet commenced, this beginning October 4. Of course one session, and particularly an initial session, is not adequate for a normal in most of these measurements. On the first evening the experimental program naturally progressed more slowly, since it was necessary to give complete instructions to all the subjects, none of whom were familiar with any of the tests. Moreover, there was a time limit beyond which it did not seem wise to extend the evening session, since the men were also to serve as subjects in the group respiration chamber during the night. It was thus impossible at first to give the full program of measurements, and hence with some tests there is no normal whatever for the men of Squad A. This condition is regrettable, but could not be avoided. Serious consideration was given to the possibility of taking measurements on Squad A after they had returned to normal and uncontrolled diet following the experiment. It will be evident to anyone who examines the data and comments which relate to the condition of Squad A during the first and second weeks following the conclusion of our investigation, that such post-diet measurements would have been unsatisfactory and could not have been considered as normal base lines. At that time the men grossly overate; many of them suffered from digestive troubles, and, in general, appeared to be indulging in what might be termed a "food spree." The period following such a

reduction in diet as these subjects underwent should be investigated for its own sake and can not be rightfully assumed as a normal. Under peace-time circumstances the men composing Squad A would usually have remained in college for two or three months subsequent to the experiment, a period which supposedly would have allowed them to become adjusted to their natural dietetic habits. At the end of such a period they doubtless could have been obtained for one or two sessions of normal measurements. It is needless to explain the impracticability of such a plan in 1918. In fact, it was exceedingly difficult to hold the subjects together until the end of the diet experiment on February 3, and in some cases it was necessary to have men excused temporarily from the Government service. Very shortly after the end of the experiment, 6 of the men in Squad A had left college and were in various fields of Government work.

Squad B did not begin the reduced diet until January 8, and remained on the low diet about 3 weeks, or until January 28. Hence, a greater part of the measurements with this squad were under supposedly normal conditions. If it is ever permissible with squads of 10 men to take the normal psychological results for one group and assume them to be a normal measure for another group, then it is permissible here. The men composing Squad A and Squad B came from the larger homogeneous body at the International Y.M.C.A. College. The men were not selected for one squad or the other on a basis of scholarship; in fact, their scholastic records show that the groups rank about evenly in this regard. Furthermore the squads compared very well in age and physical ability, although, in general, upper classmen were taken for Squad A. Doubtless, as there was some group spirit, each squad considered itself superior to the other, but as subjects for laboratory experiments in psychological measurements there was no prominent difference between them. Squad A had somewhat the advantage on the side of laboratory practice, since, in the early fall, they came regularly every 2 weeks, while the sessions with Squad B were sometimes separated by 4 weeks and the latter squad had a total number of 8 laboratory sessions, while the former squad had 10. (See chronological record, p. 60.)

With some of the measurements there are already at hand considerable normal data for comparison purposes. In the spring and early summer of 1917 a series of neuro-muscular and psychological observations were carried out at the Nutrition Laboratory with a group of 63 college men who were prospective aviators attending an aviation ground school. These subjects were mostly upper classmen or graduates from Harvard, Yale, and other leading universities. They were in many respects a picked group of men who had passed the requisite physical examination. They served one normal session of approximately 1½ hours, which followed the evening meal as did the sessions

of the reduced diet subjects. With the 63 college men of course the eating was uncontrolled. Much of the apparatus used for the low-diet research was likewise employed for the aviators. The laboratory conditions were perfectly comparable, and the procedure with the measurements was nearly identical. These data will be referred to from time to time for purposes of comparison, and will be designated as "normal series of 1917."

Since at the most the normal data with Squad A are limited to those obtained in one session, and therefore it will be necessary to refer to other data in discussing the results with these men, it will be most convenient to present the results for both squads simultaneously. The data for any measurements will be tabulated for each squad separately, but when plotted the same figure will commonly contain curves for both squads. These curves may thus be compared directly according to the number of the experiment for each squad. For example, the data for the third experiment for each squad will be plotted on the same ordinate but as Squad A had 10 sessions and Squad B only 8 the curve for the latter will be 2 points short. An effort has been made to keep the tabular presentations and the figures uniform for all the measurements so that the detailed descriptions will not have to be repeated.

Because of circumstances over which we had no control, there were certain changes in the personnel of the two groups of men. This is regrettable, particularly for the psychological measurements. Individual variations in metabolism and allied physiological processes are not so large as in these more complex functions, involving considerable learning, with which we here have to deal. All things considered, it must be counted as rare good fortune that the changes in personnel were not more frequent, and, indeed, that it was possible to hold together for so long a time 10 men in each of the two groups of 12. Statistically, 10 men is not a very large group, but practically, and considering the complexity of the research, the sacrifices that it entailed and its long duration, together with the unstable conditions in all college-student bodies in 1917–18, it is remarkable that the study was finished with so many of the original subjects still serving. A group of 10 cooperative trustworthy subjects must, all things considered, be regarded as an exceedingly satisfactory number on which to base a result in such observations. Since this is the case, it has been deemed best not to complicate the average results with the more fragmentary records from those subjects who did not serve throughout the period. It would be very difficult to equate the results for individual differences when one subject dropped out and another came into the group. Therefore, unless otherwise specified, the average for any measurement with Squad A will be the average of the individual results for the following ten subjects: *Bro, Can, Gar, Gul, Mon, Moy,*

Pea, *Pec*, *Tom*, and *Vea*. The values for *Kon*, *Spe*, and *Fre* will be given when they exist and may be compared, but are not included in the group average. The average result for Squad B will be the average of the individual records for the following 10 subjects: *Fis*, *Har*, *How*, *Ham*, *Lon*, *Liv*, *Sne*, *Tho*, *Van*, and *Wil*. The individual values, when available, will be given for *McM*, *Kim*, *Mac*, and *Sch*. It will be of interest to note occasionally how far the fragmentary records of the other subjects conform to the general findings for the group.

Although the amount of time devoted to any one measurement on an individual in an evening or morning session was rather limited, the apparatus and procedure had been arranged with a view to taking several observations of that particular kind, so that their average would be a fairly good sample of the individual's performance in that process or function. In illustration of this it will be seen as explained in the section on program and technique (p. 137) that in the measurements of the eye reactions, the word reactions, the eye movements, and the electrical threshold, particular attention had been paid to this matter. It was desired that the number of observations of a particular kind on one subject should be large enough so that some statement statistically significant regarding their consistency and uniformity might be given. When practicable, the standard deviation and coefficient of variability[1] for the individual subject and for each experiment are included in the tables, and these individual variability measures are averaged as are the other results.

We are glad to take this opportunity of acknowledging the faithful services of Miss Anna Berlin and Mr. Edward S. Mills in reading the records and in many of the computations for the large amount of psychological data.

The date on which each neuro-muscular measurement was given for the first time to the members of the two squads can be found in the chronological record of the whole experiment (p. 60). It will be further observed that for Squad B the first and second sessions (October 6 and November 3) and the third and fourth (November 17 and December 15) were in each case separated by 4 weeks. Between the fourth and fifth sessions (December 15 and January 5) there was an interval of 3 weeks. The others were separated by 2 weeks or less. All of the night observations were on Saturdays except those on January 13 and 27, which were on Sundays. January 5 was an unfavorable date experi-

[1] The standard deviation was computed by the usual formula:—$S.D.$ or $\sigma = \sqrt{\frac{\Sigma(d^2)}{n}}$. In order to compare the variability in the results for one measurement with that in a series of observations of another process, it is desirable to know the relative size of the two variability measures in terms of per cent of their respective averages or other central tendency measures. In the following tables the coefficient of variability, $C = \frac{S.D.}{M.}$ is employed, in which $S.D.$ is the standard deviation and M the arithmetical average. (See Whipple, Manual of Mental and Physical Tests, Part I, Baltimore, 1914, p. 24.)

mentally, as the men came to the Nutrition Laboratory immediately from their Christmas vacations. Starting with January 8, the diet of each man in Squad B was reduced to 1,375 net calories per day, and the men had had a total of this amount in the three meals preceding all evening psychological sessions.[1]

Except for one session, December 19, Squad A served on Saturdays, usually at intervals of two weeks. December 19 (Wednesday) was just before the Christmas vacation and the men left for their homes on December 20, immediately after the morning measurements, which in this case were electrocardiograms. Experiments on January 26 and February 2 were separated by only one week.

In comparing the neuro-muscular results for the different dates, particularly with Squad A, it will be of interest to correlate these with the values for net available energy per man during these same periods. The average net energy levels are discussed elsewhere (p. 270), and shown in the body-weight charts. Conceivably the amount of food taken on the same day when the men served in the psychological experiments of the evening would be of more immediate influence on the comfort and mental attitude of the men and so on these psychological results than the net energy figure for the days preceding this one. In arranging the experiment it was the plan to provide uniform conditions for the psychological tests. The evening meal which preceded these tests was kept standard at very nearly 700 calories for both squads and on all dates, including normal and low-diet experiments. Usually the noon meal was also standard, as the men very frequently came to Boston in the morning. The breakfast at the Nutrition Laboratory which preceded the morning tests was likewise standardized at about 640 calories for both squads on all dates. Thus the energy intake in the meal or two immediately before all the psychological sessions was uniform and at an average low level. The breakfasts in Springfield changed considerably in accordance with the fluctuations in the weight of the subjects, as it was the custom in the investigation to adjust the food to weight mostly in this meal. The data (see table 146) for the net available calories per man on those days when the members of Squad A came to Boston and had evening psychological measurements show for any subject considerable variations from date to date which are largely the differences in breakfasts. The individual averages for October 13 to February 2, inclusive—*i. e.*, for all but September 29—are given at the bottom of the table; below this are found the averages for net available calories throughout the whole low-diet experiment, exclusive of the Thanksgiving and Christmas vacations. These latter individual averages for the experiment are in every case larger than

[1] For details of the standard meals given in Boston, see tables 25, 26, and 27, pp. 262 and 263. On dates previous to January 8, members of Squad B were eating uncontrolled and supposedly had about 3,800 net calories per day per man.

those for the 9 days, mostly because they include the uncontrolled Sundays, which were the farthest possible removed from the psychological sessions.

The individual energy values in table 146 are lowest on November 10. This general average of 1,390 calories is higher, however, on account of the standard evening meal than the energy for the two preceding days, November 8 and 9. The reverse will be found true if a like comparison is made for December 19. Thus the constant factor of the standard meals taken before the psychological tests minimizes the fluctuations and tends to place all the psychological results on a more comparable and uniform level.

TABLE 146.—*Net available calories per man on those days when the members of Squad A cam to Boston and had evening psychological tests.*

Date.	Day.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.
1917.									
Sept. 29	Sat......	[2]3,049	[2]3,123	....	[2]3,142	[2]3,177	[2]3,155	[2]3,074	[2]3,127
Oct. 13.....	Sat......	2,051	2,049	....	2,049	2,107	2,075	1,783	1,968
Oct. 27.....	Sat......	1,679	1,507	....	1,521	1,684	1,634	1,616	1,619
Nov. 10.....	Sat......	1,402	1,647	1,321	1,406	1,273	1,410	1,300	1,470
Nov. 24.....	Sat......	1,478	1,902	1,499	1,660	1,386	1,329	1,354	1,819
Dec. 8.....	Sat......	1,785	2,281	1,357	2,083	1,542	2,002	1,560	2,054
Dec. 19.....	Wed.....	2,331	2,567	1,927	2,475	1,832	2,605	1,586	2,550
1918.									
Jan. 12.....	Sat......	1,536	2,046	1,520	1,517	1,577	1,501	1,474	1,530
Jan. 26.....	Sat......	1,927	2,075	1,739	2,016	1,935	1,959	1,608	2,061
Feb. 2.....	Sat......	1,870	1,825	1,616	1,871	1,620	1,706	1,636	1,962
Individ. av.[3].	....	1,784	1,989	1,526	1,844	1,662	1,802	1,546	1,893
Individ. av.[4].	....	1,885	2,102	1,570	1,874	1,787	2,020	1,822	2,067

Date.	Day.	Pec.	Spe.	Tom.	Vea.	Fre.	Gen. av.	Regular av.[1]
1917.								
Sept. 29[2]....	Sat......	[2]3,117	[2]2,208	[2]3,082	[2]2,821	[2]3,089	[2]3,097	[2]3,087
Oct. 13.....	Sat.......	2,003	2,062	1,806	2,043	1,790	1,982	1,993
Oct. 27.....	Sat......	1,554	1,542	1,564	1,578	....	1,591	1,596
Nov. 10.....	Sat......	1,374	1,377	1,362	1,333	....	1,390	1,398
Nov. 24.....	Sat.......	1,458	1,905	1,440	1,425	....	1,555	1,525
Dec. 8.....	Sat......	1,444	1,659	1,460	1,578	....	1,734	1,779
Dec. 19.....	Wed.....	2,033	....	1,855	1,755	....	2,138	2,159
1918.								
Jan. 12.....	Sat......	1,897	....	1,116	1,539	....	1,568	1,573
Jan. 26.....	Sat......	1,775	....	1,701	1,908	....	1,882	1,897
Feb. 2.....	Sat......	1,597	....	1,720	1,875	....	1,754	1,768
Individ. av.[3].	....	1,682	1,709	1,558	1,670	....	....	1,743
Individ. av.[4].	....	1,728	1,964	1,625	1,767	....	....	1,852

[1] This average does not include *Kon*, *Spe* and *Fre*.
[2] Assumed from average calories for normal period Oct. 1–4.
[3] For above nine days during reduced-diet period.
[4] For whole reduced-diet period exclusive of Thanksgiving and Christmas vacations.

In amount of available energy received, the men rank as follows, the first line showing the order for the averages of the 9 days on which evening psychological experiments were made with Squad A during the low-diet period and the second line gives their rank during the whole experiment.

Can,	Pea,	Gar,	Mon,	Bro,	Spe,	Pec,	Vea,	Gul,	Tom,	Moy,	Kon.
Can,	Pea,	Mon,	Spe,	Bro,	Gar,	Moy,	Gul,	Vea,	Pec,	Tom,	Kon.

Thus, *Can* regularly had more food than any of his fellows and *Kon* averaged the least. There is fairly good agreement in the relative size of the energy figure for each subject. The daily averages at the extreme right in the lower part of table 146 are for the 10 men whose records are to be averaged in the psychological results which follow. Inspection of the table shows a gradual decrease to 1,398 calories on November 10. There is an increase on the next three dates to 2,159 calories for December 19. Following the Christmas vacation, a decrease to 1,573 calories was necessary on January 12; the intake was larger in the latter part of January. This table will be found convenient for comparison with the results in the different measurements; it represents individual days and the values must not be confused with those shown in the body-weight charts which cover rather large groups of days.

GROUP PSYCHOLOGICAL MEASUREMENTS.

In discussing the results, those measurements given by the group method will be first considered. They are treated in their approximate order of complexity, as numbered and tabulated on page 139.

(1) ACCURACY IN TRACING.

The data for this simple motor test are embodied in tables 147 and 148 for Squads A and B, respectively. At the left in chronological order are found the dates for the evening experimental sessions. The data for the various subjects are arranged in columns from left to right. The headings of these columns are the abbreviated names of the subjects. The subjects are always listed in the same order, that is, with Squad A, beginning with *Bro* and ending with *Fre*. The latter subject served the shortest time, that is, the fewest number of sessions of any one in either squad, and with some measurements there are no data for him. *Kon*, who was originally a member of Squad B, replaced *Fre*, who left Squad A on October 26. *Kon* served his first session October 6 as subject No. 5 in Squad B. His data for this evening are transferred to the tables for Squad A and given under the date of September 29, the first session for Squad A. *Fre* was present at the Laboratory at the second session with Squad A, that is, October 13, so that *Kon* actually came into Squad A at a later date. He began his diet reduction on October 30, and since the percentage reduction was very rapid, it seems best not to average the results for *Kon* with

Squad A. *Spe*, owing to illness (see p. 360), was not present at the Laboratory after December 8, and his place was not filled. In Squad B, *Fis* was in the hospital for an operation for hernia on December 15. *McM* was not taken into Squad B until after their first session on October 6, when he replaced *Kon*. In the early part of January he had some digestive difficulties which made it seem unwise for him to serve as a subject during the severe food reduction for this squad. His place was taken by *Kim*, who had served on January 5 in place of *Lon*. *Lon* on that date was ill and it was possible that he might not be able to continue as a subject in Squad B. *Mac* was called into the Government service during the Christmas vacation, receiving his notification only the day before it was necessary for him to appear at camp. We were not informed of his call until after he had been at camp several days. An arrangement was made with the commandant to release him until the first of February. The subject thought that this short interval in college would be of little value, and, as he was well started

TABLE 147.—*Squad A—Accuracy of movement in tracing.* (*Average number of errors per line.*)

Experiment.	Bro.	Can	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre	Av.[1]
1917														
Sept. 29[2]	5.3	6.0	7.0	6.1	5.1	6.9	4.5	7.4	8.2	7.8	2.4	5.8	6.0	5.7
Oct. 13	4.0	6.2	....	7.0	7.6	5.7	4.2	10.2	7.4	6.8	2.8	4.2	4.8	5.9
Oct. 27	2.6	5.8	10.8	4.4	7.0	9.0	7.8	10.0	9.4	7.6	1.8	2.6	....	6.0
Nov. 10	3.0	6.6	7.2	4.4	3.4	7.8	5.8	8.0	10.6	6.8	1.6	2.6	....	5.4
Nov. 24	2.8	9.0	6.4	3.6	5.8	8.0	6.6	6.4	7.4	4.4	1.0	2.2	....	5.3
Dec. 8	1.2	4.4	5.6	5.0	4.2	4.7	3.4	6.6	7.0	6.1	1.6	2.8	....	4.1
Dec. 19	1.2	5.7	6.8	4.0	5.0	6.8	5.4	6.4	7.6	....	2.2	2.8	....	4.7
1918.														
Jan. 12	1.8	4.8	5.4	4.6	4.8	8.5	7.2	4.8	4.0	....	2.0	1.6	....	4.4
Jan. 26	1.4	3.9	5.1	3.0	3.0	6.4	4.2	5.2	4.2	....	2.8	1.0	....	3.3
Feb. 2	2.2	4.2	5.2	2.6	2.4	5.2	3.2	5.4	6.6	....	2.4	[3]0.6	....	3.3
Low-diet av.[2]	2.2	5.6	6.5	4.3	4.8	6.9	5.5	7.0	7.1	6.3	2.0	2.3	4.8	4.7

[1] This average does not include *Kon*, *Spe* and *Fre*.
[2] The one normal experiment, Sept. 29, is not included in the average.
[3] It is worthy of notice that *Vea*, who made this best score and one of the best average scores, suffered most from cold hands during the low-diet period.

in his work, he did not see fit to leave it to carry on the experiment. A substitute was found in *Sch*, who served in the last four sessions of Squad B. *Tho*, in returning from his Christmas vacation, was delayed, and because of transportation conditions could not reach the Laboratory on the evening of January 5 until after the group work had been completed. These breaks or irregularities in all our psychological data occur in the succeeding tables for other measurements and will not need special mention there.

The values given in tables 147 and 148 show the average number of errors per line. Each average represents five lines, as the test

blank was so made up. In table 147, the scores range from 0.6 to 10.8. The total average is approximately 5. The individual differences may be seen in the averages in the bottom line of the table. Each value is from the nine low-diet results in the column above. As September 29 was normal, it is never averaged with the other dates. The average at the bottom of the table covers the low-diet period and for convenience is called low-diet average. *Tom*, *Bro*, and *Vea* made the best scores. The values were: 2.0, 2.2, and 2.3. *Tom* was very consistent throughout. He made decidedly the best records in the early sessions, but did not keep his lead owing, no doubt, to his physical condition as a result of the operation which came near the end of the experiment. The scores of *Pea* may have been affected by the fact that a few hours before he came to Boston he usually engaged in a cross-country race. It may be of significance that when *Kon* showed the poor score of 10.8, he was practically fasting.

In table 148, which gives the results for Squad B, the range of variation is about the same, that is, from 0.6 to 11.7. The upper 5 dates

TABLE 148.—*Squad B—Accuracy of movement in tracing. (Average number of errors per line.)*

Experiment.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.[1]
1917.															
Oct. 6	11.7	2.9	3.5	3.8	....	....	8.4	3.3	....	2.3	2.6	4.5	6.4	9.6	5.6
Nov. 3	11.0	4.2	4.6	5.6	6.1	....	6.7	5.8	....	3.9	3.6	5.3	3.5	7.8	5.6
Nov. 17	7.2	2.6	3.6	6.8	5.1	....	6.4	1.5	....	2.4	2.6	2.6	4.6	7.2	4.6
Dec. 15	....	2.9	2.2	7.2	4.6	....	7.6	2.7	....	4.0	3.8	2.6	4.0	7.6	4.7
1918.															
Jan. 5	5.8	5.8	2.6	5.4	3.4	8.4	....	....	9.4	4.8	1.2	....	4.3	8.8	4.8
Normal av.	8.9	3.7	3.3	5.8	4.8	8.4	7.3	3.3	9.4	3.5	2.8	3.8	4.6	8.2	5.1
Jan. 13	7.2	5.4	2.6	5.0	....	10.8	6.2	....	7.2	5.1	0.6	2.0	3.1	6.6	4.4
Jan. 19	6.0	4.4	1.2	4.4	....	6.2	4.6	....	7.2	1.4	2.4	1.2	1.5	8.2	3.5
Jan. 27	4.8	5.6	2.2	4.6	....	5.4	5.6	....	5.3	4.0	2.4	2.6	2.2	5.4	3.9
Low-diet av.	6.0	5.1	2.0	4.7	....	7.5	5.5	....	6.6	3.5	1.8	1.9	2.3	6.7	3.9

[1] This average does not include *McM*, *Kim*, *Mac*, and *Sch*.

at the left hand of the table were normal; the 3 lower ones were during food reduction. The two groups of records have been averaged separately for each individual. The best records were made by *Sne*, *How*, and *Tho*. The low-diet averages for each individual, with the exception of a few cases, show that during the low diet the subjects continued to improve in the test, with the result that they made fewer errors. This was not the case with *Har*, who had a normal average of 3.7 and a low-diet average of 5.1, and *Liv*, who averaged 3.5 under both conditions. The average score for both groups of men, Squads A and B, is, if anything, a little smaller than the scores reported by Fisher and

Berry, who used this same test in an investigation carried out at the International Y. M. C. A. College in 1915.[1]

The average results for both squads, considered together, are shown in figure 102. The upper horizontal line of dates at the top of the figure, beginning September 29, October 13, etc., is for the sessions of Squad A (see table 147). September 29 is the only normal date, the others representing a reduced diet. The lower horizontal line of dates beginning October 6, November 3, etc., is for the sessions of Squad B. The first five of these, that is, until and including January 5, were normal sessions (uncontrolled diet). The last three, January 13, 19, and 27, were under conditions of reduced diet when the reduction was much more pronounced than usual for Squad A. On September 29, the one normal date, Squad A had an average value of 5.7. On the two succeeding dates, October 13 and 27, separated by 2-week intervals, the average errors were somewhat larger, 5.9 and 6.0; several of the men made their poorest records on October 27. Other subjects—*Can*, *Gul*, and *Pea*—showed very little improvement over the previous two sessions. The improvement was not what would be expected nor equal to that found with Squad B and shown by the curve in figure 102. Squad B, it is true, showed no improvement between the first two sessions, but a period of four weeks elapsed between the two experiments of October 6 and November 3. Between the second and third sessions the period was exactly two weeks; much improvement was shown, the errors being reduced to 4.6. Between sessions 3 and 4 a period of a month again elapsed and no improvement is shown. The same is to be said for sessions 4 and 5, which were separated by 3 weeks. When the sessions were separated by two weeks or less an improvement in accurate tracing with Squad B almost always resulted. While the two curves start at nearly the same point, it is evident that, considering the number of practices and the intermissions, Squad B made definitely the better performance. Squad A did as well as Squad B at the sixth session, that is December 8 for Squad A and January 13 for Squad B. This abnormal rise for Squad A is associated with the more comfortable period in the early part of December, when the men were receiving more food. December 19, which shows a depression in the curve, was probably influenced by the fact that the observations on this date immediately preceded the Christmas vacation. On January 12 the net energy given the subjects was small to counterbalance the overeating during the vacation period. On the last two dates, January 26 and February 2, the group made their best records. It is unfortunate that the experiments with Squad B did not come with the same regularity and were not equal in number to

[1] Fisher and Berry, Physical Effect of Smoking, New York, 1917. These authors state that a fountain pen was used for drawing between the lines, that a metronome was employed to time the men, and that 17 seconds were allowed for each line. Professor Berry informs us that "17" is a misprint and the time should be 14 seconds, the same as that used in our investigation.

those with A. It is, furthermore, unfortunate that the last normal date for this squad (January 5) was the immediate close of the vacation period and was separated from their previous experiment by 3 weeks. The conditions in the two observations preceding the food reduction with Squad B are not favorable for revealing the influence of the 3 weeks of reduced diet. Notwithstanding this, it is evident from the curve in figure 102 that up to the sixth experiment, in spite of the longer intervals between experiments, Squad B shows a superior performance to Squad A. At the sixth experiment, the first in the reduced-diet period for Squad B, they are slightly poorer than Squad A, and in their next two, January 19 and 27, while they improve over January 13, they do not reach the record of Squad A for January 26 and February 2, which, considering their superiority over Squad A in experiments 2 to 5 inclusive, they might reasonably have been expected to reach.

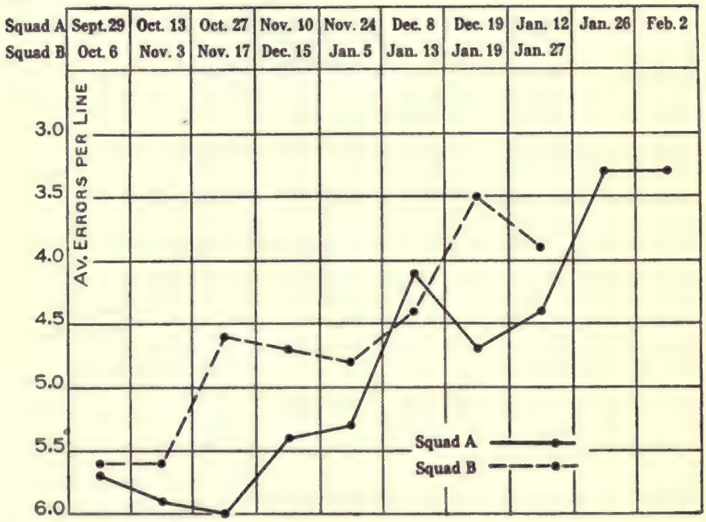

FIG. 102.—Errors in accuracy of tracing between parallel lines.

It seems justifiable to conclude, although the results for Squad B, unless interpreted in the light of certain modifying conditions, will not entirely support the statement, that with Squad A, particularly during the months of October and November, the motor functions involved in steadiness in tracing as used in this test were interfered with by the reduced diet, since the squad as a whole did not do such accurate work or make such rapid improvement in the test as would have been expected of them under normal conditions.

(2) DISCRIMINATION FOR THE PITCH OF TONES.

Seashore and his collaborators[1] have concluded as a result of a great deal of experimentation that the ability to discriminate the pitch of tones is elemental and the sensitiveness of the ear to pitch dif-

[1] Seashore, Psychological Monographs, 1910, **13**, p. 53; Smith, F. O. (Iowa Studies in Psychology, **6**), Psychological Monographs, 1914, **16**, pp. 67 to 103, particularly p. 101; Seashore and Mount (Iowa Studies in Psychology, **7**), Psychological Monographs, 1918, **15**, pp. 47 to 92; also, Seashore and Tan, *ibid.*, pp. 159 to 163.

ferences can not be improved appreciably by practice. They distinguish sharply between the cognative and physiological thresholds. The cognative threshold shows rapid improvement at first and approaches the physiological threshold just to that degree that the subject is able to grasp the nature of the test, to understand thoroughly what is required of him, remove subjective disturbances, expectations, and inhibitions, and to summon his best effort and most favorable attention to the discrimination of the *pitch* of the tones presented.

These experimenters believe that a 1-hour group test by the heterogeneous method (that is, a number of individuals who have not been classified in reference to their pitch discrimination ability, tested with a number of pitch differences ranging in size from 30 to 1 vd.,[1] and each increment presented for judgment about an equal number of times) will reveal the approximate physiological threshold of about half of the subjects tested. The elimination of all objective disturbances, careful instruction, and the ingenuity of the experimenter count for much.

In using pitch discrimination as a measurement in the present research, it was not hoped to make an accurate determination of the physiological threshold of the subjects tested to ascertain if food reduction changed this physiological constant. The time would not permit of using the measurement in any other way than by the group method. In the first test with each squad pitch difference increments of 30, 23, 17, 12, 8, 5, 3, 2, and 1 vd. lower than 435 vd. were employed. The test lasted about one-half hour. Judging by previous experience with pitch discrimination measurements, the conditions were favorable. Nearly all the subjects were able to discriminate, without error, differences above 8 vd. In succeeding tests it was therefore possible to confine the judgments to intervals of 8, 5, 3, 2, and 1 vd. It would have been possible also to have omitted the increment of 8 vd., since nearly all subjects show from 90 to 100 per cent correct judgment with this pair of tuning forks. It was, however, advantageous to use this increment in the test because of the easy assurance with which the subject was able to judge between these tones. This gave confidence for the more difficult judgments.

In tables 149 and 150 for Squads A and B, respectively, the percentages of correct judgments are given for the pitch increments 5, 3, 2, and 1 vd.[2] The tables are of the same general form as those given for steadiness of tracing. Thus in table 149 *Bro* on October 13 shows 97 per cent correct judgment with a pitch difference of 5 vd., 90 per cent with a difference of 3, 80 per cent for 2, and 63 per cent for a difference of 1 vd. This was the second trial in pitch discrimination

[1] Double vibrations.

[2] It appeared unnecessary to include the results for 8 vd., as the percentage of correct judgments with this interval was usually well above 90.

for this subject, and his record shows considerable improvement for the same pitch increments over his trial on September 29, when, as described, the larger increments were used and fewer trials were made with each. There are a large number of values scattered through the

TABLE 149.—*Squad A—Percentage of correct judgments in pitch discrimination.*

Date.	Intervals.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.[1]	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.[1]
1917.	*vd.*														
Sept. 29..	5	70	70	90	80	100	70	100	80	90	90	100	90	100	87
	3	50	80	60	60	80	50	50	70	80	50	60	60	50	66
	2	70	80	50	60	90	70	70	70	50	80	50	60	50	67
	1	40	40	50	60	40	50	40	30	60	40	70	50	30	48
Oct. 13..	5	97	80	....	90	100	63	87	93	100	97	97	93	100	93
	3	90	70	....	90	97	67	90	87	93	87	83	80	80	87
	2	80	63	....	63	80	50	70	70	53	57	77	73	67	70
	1	63	57	....	47	60	47	50	73	60	53	60	60	67	59
Oct. 27..	5	100	77	93	97	100	80	80	100	97	97	90	90	....	92
	3	97	73	77	93	100	27	87	87	97	97	83	83	....	89
	2	77	80	60	77	93	47	73	80	87	87	73	70	....	79
	1	57	73	53	83	87	40	77	83	83	83	67	53	....	74
Nov. 10..	5	100	83	100	100	100	60	83	100	90	100	100	97	....	95
	3	97	80	83	97	100	60	80	100	93	97	100	87	....	93
	2	93	60	70	80	97	43	53	90	63	93	90	83	....	79
	1	77	83	63	83	93	37	43	83	67	83	83	67	....	75
Nov. 24..	5	100	90	100	97	100	27	100	100	97	97	97	97	....	98
	3	97	87	87	100	100	47	83	100	100	100	87	67	....	91
	2	90	73	77	97	100	37	70	83	87	83	87	80	....	85
	1	67	73	63	97	83	23	63	70	90	63	70	53	....	74
Dec. 8..	5	100	83	90	93	100	40	97	100	100	100	100	100	....	97
	3	97	63	80	90	97	20	83	90	100	97	80	73	....	86
	2	73	77	80	73	100	23	60	70	93	97	77	77	....	78
	1	53	67	57	80	73	30	53	70	63	87	53	53	....	63
Dec. 19..	5	97	63	97	100	100	63	97	97	97	....	97	87	....	93
	3	93	73	93	93	100	43	87	93	90	....	63	80	....	86
	2	90	77	80	90	93	40	70	83	57	....	77	60	....	77
	1	60	53	53	67	77	27	50	67	63	....	57	50	....	60
1918.															
Jan. 12..	5	97	90	100	90	100	83	87	100	97	....	97	100	....	95
	3	90	73	87	77	100	50	73	93	90	....	70	80	....	83
	2	67	67	83	83	93	60	63	87	87	....	60	67	....	75
	1	70	47	57	70	70	40	57	67	80	....	53	57	....	63
Jan. 26..	5	97	87	97	97	97	50	87	97	90	....	100	97	....	94
	3	90	87	93	93	97	40	90	90	93	....	60	70	....	86
	2	83	50	83	73	83	53	70	77	87	....	60	63	....	72
	1	63	63	43	83	70	40	60	80	70	....	53	53	....	66
Feb. 2..	5	100	80	100	93	100	60	83	100	97	....	97	100	....	94
	3	100	87	90	93	97	43	87	100	90	....	90	87	....	92
	2	87	43	83	60	97	60	63	80	80	....	67	87	....	74
	1	73	60	57	80	77	37	60	90	77	....	63	60	....	71
Low-diet av.[2]....	5	99	81	97	95	100	58	89	99	96	98	97	96	100	95
	3	95	63	83	92	99	44	84	93	94	91	79	79	80	88
	2	82	66	74	77	91	46	66	80	77	83	74	73	67	77
	1	65	64	55	77	77	36	57	76	73	74	62	56	67	67

[1] Records for *Mon* show low and irregular values and were not included in the average which also excludes *Kon, Spe,* and *Fre.*

[2] Sept. 29 (normal) not included in this average.

table that show 100 per cent correct judgment. These are usually with increments of 5 and 3 vd. *Gul* had a final average (see average at bottom of table 149) of 100 per cent correct judgment with 5 vd., 99 per cent with 3, with 91 per cent and 77 per cent for 2 and 1 vd., respectively. Conventionally, the pitch discrimination threshold is considered to be that difference or increment which shows 75 per cent of correct judgment. According to this, *Gul's* threshold was 1 vd.

TABLE 150.—*Squad B—Percentage of correct judgments in pitch discrimination.*

Date.	Intervals.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.[1]	Wil.	Av.[1]
1917.	*vd.*															
Oct. 6..	5	70	80	60	90	....	....	80	90	....	80	80	90	80	100	81
	3	70	80	80	50	....	....	40	70	....	70	90	90	60	100	74
	2	70	70	60	80	....	....	60	60	....	60	60	80	50	90	70
	1	50	40	60	50	....	....	40	40	....	60	60	70	10	80	57
Nov. 3..	5	90	80	87	90	77	....	93	87	....	83	93	100	43	100	91
	3	83	93	73	83	70	....	87	87	....	67	77*	97	17	100	84
	2	77	77	50	53	87	....	67	70	....	57	70	90	30	83	69
	1	63	57	40	53	60	....	47	60	....	50	60	67	33	83	58
Nov. 17..	5	97	90	90	97	47	....	100	97	....	87	100	100	70	100	96
	3	87	93	80	80	47	....	83	93	....	83	93	97	40	100	88
	2	67	77	73	73	50	....	70	67	....	70	83	93	33	90	77
	1	50	73	43	43	37	....	47	40	....	43	57	67	37	87	57
Dec. 15..	5	....	77	73	80	57	....	100	97	....	87	97	100	77	100	89
	3	....	80	67	80	53	....	87	90	....	67	93	87	57	100	83
	2	....	73	60	70	47	....	70	70	....	70	73	83	37	97	75
	1	....	67	47	60	40	....	57	53	....	70	77	77	47	90	68
1918.																
Jan. 5..	5	97	93	97	97	57	100	....	....	67	83	93	....	70	93	93
	3	77	80	90	70	47	100	....	....	67	83	87	....	67	97	83
	2	63	77	73	67	60	77	....	....	57	63	67	....	70	90	71
	1	67	80	67	60	53	57	....	....	60	50	77	....	57	73	68
Normal av...	5	88	84	81	91	60	100	93	93	67	84	93	98	68	99	90
	3	79	85	78	73	54	100	74	85	67	74	88	93	48	99	82
	2	69	75	63	69	61	77	67	67	57	54	71	87	46	71	72
	1	58	63	53	53	48	57	48	48	60	55	66	70	37	83	62
Jan. 13..	5	93	80	97	100	....	100	97	....	50	90	93	100	83	100	94
	3	87	80	83	80	....	100	73	....	40	93	100	87	60	97	87
	2	83	60	63	87	....	90	60	....	50	70	80	53	57	93	72
	1	66	50	50	47	....	70	57	....	53	57	53	63	73	87	58
Jan. 19..	5	100	90	87	83	....	100	83	....	73	90	97	93	80	100	91
	3	90	100	73	73	....	100	70	....	37	80	97	97	80	100	87
	2	70	60	50	67	....	83	50	....	43	43	80	67	83	100	65
	1	63	57	60	47	....	63	50	....	37	60	70	43	53	90	60
Jan. 27..	5	100	97	80	90	....	100	93	....	60	97	100	100	90	100	95
	3	90	90	77	70	....	93	40	....	50	77	90	93	60	100	81
	2	77	83	63	63	....	93	47	....	40	53	73	73	43	77	68
	1	70	67	63	50	....	70	57	....	43	43	80	70	57	60	62
Low-diet av...	5	98	89	88	91	....	100	91	....	61	92	97	98	84	100	93
	3	89	90	78	74	....	98	61	....	42	83	96	92	67	99	85
	2	77	68	59	72	....	89	52	....	44	55	78	64	61	90	68
	1	64	58	58	48	....	68	55	....	44	53	68	59	61	79	60

[1] Besides *McM*, *Kim*, *Mac*, and *Sch*, subject *Van* is also excluded from this average, as he shows low and irregular values.

or slightly below. *Gar* also shows 77 per cent at 1 vd. His record, however, is not so consistent, since he showed 77 per cent also for 2 vd. Other average records which are particularly good are with subjects *Pea*, *Pec*, and *Bro*, all of whom have thresholds below 2 vd. *Kon*, *Tom*, and *Vea* show almost exactly 75 per cent on 2 vd. The values for *Mon*, since they frequently show less than 50 per cent correct judgments, were in the case of pitch discrimination not included in the averages which are for the other 9 regular subjects and appear at the right of the table. The total average for all records, excluding September 29 (normal), shows 95, 88, 77, and 67 per cent correct judgment for pitch-difference intervals 5, 3, 2, and 1 vd., respectively. The average threshold is evidently very close to 2 vd., which corresponds absolutely with the modal threshold found by Seashore from records on about 800 undergraduate college students, including both men and women.

The data in table 150 for Squad B show no marked peculiarities which differentiate them from those for Squad A. There was considerable improvement between the first and second dates, October 6 and November 3, although these were separated by one month. Individual averages for the 5 normal periods are on the whole not quite so high as those shown for the 9 periods for Squad A. As many of the values for *Van* are below 50 per cent, they have not been included with the others in the group averages. The averages for the remaining 9 regular subjects show a total for the normal period of 90, 82, 72, and 62 per cent correct judgment for intervals 5, 3, 2, and 1 vd., respectively. Again, 2 vd. appears to be very near the normal threshold for this group.

The total comparable averages for intervals 5, 3, 2, and 1 vd. for the two squads on the different dates are most conveniently compared in diagrammatic form, as in figure 103. The 8 curves give a somewhat confusing appearance to the figure. It will, however, be seen that the results for the different increments are for a particular squad at different levels. The four curves for Squad B do not touch or cross each other at any point, showing consistently the increasing difficulty of increments 5 to 1 vd., since on each date the percentage of correct judgments regularly decreases. The same is true for the four curves of Squad A, with the single exception of the curves for 3 and 2 vd. on September 29, which begin at almost the same point. The confused appearance is therefore due to the fact that the two squads in general have so nearly the same level for the different pitch-discrimination increments.

In the case of 5 vd. the two curves ascend about equally between the first and second experiments and thereafter maintain approximately the same level, which is very near 95 per cent. Squad B shows some depression on December 15, due to the unaccountably poor records for

Har and *How* of 77 and 73 per cent (see table 150), which are considerably lower than usual for these two subjects. From the fifth session to the close of the experiment the two squads show uniform results.

With 3 vd., improvement is evident between the first and second experiments, Squad B indicating about the same improvement as with 5 vd. Squad A shows considerable improvement, but this is due to the unexplainable fact that the threshold for 3 vd. on September 29 was abnormally low. The record for several of the subjects, *i. e.*, *Bro*, *Moy*, *Gar*, *Tom* and *Vea*, is only 50 to 60 per cent correct judgment (see table 149). Some improvement is evident in the next two sessions (experiments 3 and 4). The decline in experiment 5 of itself is perhaps not significant, but it is the beginning of the depression in the curve during the next four sessions, that is, December 8 to January

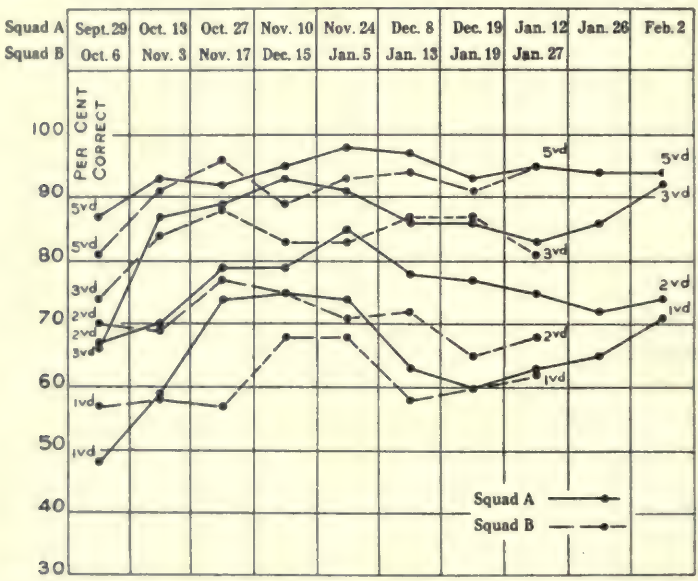

FIG. 103.—Percentage of correct judgments in discriminating the pitch of tones.

26, which is fairly well marked. There is recovery to the highest level on February 2. Squad B shows depression for 3 vd. on December 15 and January 5, that is, just before and just following the Christmas vacation, with a drop on January 27.

For 2 vd. the curves start at about the same level; there is almost no improvement between the first and second experiments; there is, however, considerable improvement between the second and third experiments. Specifically, Squad A continued to improve after this date and reached their highest value on November 24. From December 8 to the end of the experiment there was a decrement. Squad B showed a decrease on January 5, to a score of 71 per cent. January 13, the first

reduced-diet date, was at about the same level, and on the following two dates the values are still lower; in fact, lower than for the first and second experiments.

With 1 vd. Squad A showed considerable improvement at the start. Their first threshold was, however, undoubtedly too low, being only 48 per cent. Their maximum level was attained in the third, fourth, and fifth sessions and maintained very evenly. Beginning with December 8 there was a marked depression, with some recovery on January 26 and February 2, especially on the latter date, but it did not reach the former level. Squad B shows a continuing low level for the first three sessions. The expected improvement from practice with this most difficult judgment of the series does not reach a maximum in the third test as do the other curves for this squad but, as might naturally occur, is delayed until the fourth and fifth sessions. The remaining points in the curve represent January 13, 19, and 27, the food reduction period, when there was a considerable decrease in the percentage of correct judgments with the 1 vd. interval.

In this pitch discrimination test, the records of most interest are those for the increments 3, 2, and 1 vd., which were near the threshold value and thus required the greatest care and attention for correct judgment. The average results for Squad B are fairly consistent in demonstrating poorer discrimination during the low-diet period. This is quite noticeable in the two smallest increments. For Squad A an adequate base line is lacking but beginning with December 8, these men on the average not only failed to improve over former results but for the remainder of the research show a general decrement, which is associated with the prolongation of the reduced diet régime.

(3) DISCRIMINATION FOR SPECIFIED NUMBER GROUPS.

As described on page 145, the subject was required to mark in each line of 10 numbers every combination of 2 successive digits which added together equaled 11. In correcting the records, three things were noted: (1) the number of combinations found and correctly marked in that part of the material which the subject was able to cover in 5 minutes; (2) the number passed over unmarked by the subject; and (3) the number of incorrect combinations marked. It will be recalled that the same amount of new material was provided the subjects at each test, the quantity having been from the first experiment made large enough so that no subject would be likely to complete the material efficiently in the 5-minute period allowed. Each man began at the first of the blank and proceeded as far as he could within the time limit. In succeeding trials, as the men gained in proficiency and became thoroughly familiar with the number combinations to be marked, they covered more and more of the material provided. It is therefore clear that the sum for combinations marked and combinations passed unmarked (errors of omission) will not be the same from day to day but is a meas-

ure of the amount of material covered and depends upon the speed and accuracy of each subject. Tables 151 and 152 give the individual data for all the subjects of Squads A and B. The tables are arranged in the usual form, with the dates in chronological order at the left, and column headings giving the subjects in order. The breaks discussed on page 557 likewise occur in these data. Incorrect combinations were marked by members of either squad in only a few instances, as with

TABLE 151.—*Squad A—Cancellation of specified number groups.*

Date and number groups.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.[1]
1917.														
Sept. 29:														
Found	28	26	23	27	47	37	25	48	25	10	40	44	34	34.7
Missed	8	17	5	2	30	19	4	16	15	5	4	20	10	13.5
Mistakes	0	0	0	1	1	0	0	0	0	2	1	0	0	.3
Oct. 13:														
Found	56	39	....	40	76	65	43	63	45	30	50	72	59	54.9
Missed	14	26	....	51	64	20	10	26	28	9	20	16	29	27.5
Mistakes	0	4	....	3	0	0	2	0	0	0	2	0	0	1.1
Oct. 27:														
Found	68	49	44	60	89	68	51	80	61	39	47	78	....	65.1
Missed	12	7	15	11	50	13	8	25	26	2	7	10	....	16.9
Mistakes	0	1	0	0	0	0	1	0	0	0	0	0	....	.2
Nov. 10:														
Found	65	60	56	62	77	78	43	88	55	33	53	84	....	66.5
Missed	6	12	5	6	28	9	14	14	27	10	10	21	....	14.7
Mistakes	0	4	0	0	0	0	0	0	0	0	0	0	....	.4
Nov. 24:														
Found	75	65	62	67	96	73	41	91	62	34	56	100	....	72.6
Missed	3	13	3	10	62	25	26	8	22	4	11	6	....	18.6
Mistakes	0	3	0	0	0	0	1	0	0	0	2	0	....	.6
Dec. 8:														
Found	81	71	65	67	121	72	59	82	70	45	60	85	....	76.8
Missed	5	15	7	10	24	30	11	7	17	9	12	4	....	13.5
Mistakes	0	1	0	0	0	0	0	0	0	0	0	0	....	.1
Dec. 19:														
Found	80	70	68	72	113	75	54	89	68	....	60	98	....	77.9
Missed	4	7	4	14	29	21	24	18	20	....	13	6	....	15.6
Mistakes	0	0	0	0	0	0	0	0	0	....	0	0	....	0
1918.														
Jan. 12:														
Found	79	69	66	72	76	71	56	76	61	....	60	107	....	72.7
Missed	4	13	5	7	82	37	14	13	23	....	14	11	....	21.8
Mistakes	0	0	0	0	0	0	0	0	0	....	0	0	....	0
Jan. 26:														
Found	89	75	72	75	119	77	58	101	68	....	65	106	....	83.3
Missed	4	14	12	9	34	22	14	8	19	....	22	13	....	15.9
Mistakes	0	0	0	0	0	0	0	0	0	....	0	0	....	0
Feb. 2:														
Found	98	71	77	79	118	83	71	106	74	....	75	115	....	89.0
Missed	2	14	4	7	25	22	10	16	17	....	17	4	....	13.4
Mistakes	0	0	0	0	0	0	0	0	0	....	0	0	....	0
Low-diet av.:														
Found	76.8	63.2	83.8	66.0	98.3	73.6	52.9	86.2	62.7	36.2	58.4	93.9	59	73.2
Missed	6.0	13.4	6.9	13.9	44.2	22.1	14.6	15.0	22.1	6.8	14.0	10.1	29	17.5
Mistakes	0	1.4	0	.3	0	0	.4	0	0	0	.4	0	0	.3

[1] These averages do not include the records for *Kon*, *Spe*, and *Fre*.

Can.[1] Some of the desired number combinations were always passed over in the material which was covered. The best records in this respect are those for *Gar*, September 29; *Spe*, October 27; and *Bro*, February 2, when in each case there were two errors of this sort. *Lon*, *Sne*, *Tho*, and *Wil*, all of Squad B, made individual records with as small a number as 3 errors of omission. The low-diet averages for Squad A show in number of combinations correctly marked a range from 52.9[2] in the case of *Moy* to 98.3 for *Gul*. The averages for combinations missed range from 6.0 for *Bro* to 44.2 for *Gul*. The latter usually missed many of the combinations; on January 12 his omissions were 82. The low-diet average for the group of 10 men is 73.2 combinations checked, 17.5 combinations missed; the number wrongly checked is negligible.

Squad B (see table 152) for the average of normal experiments show a range for combinations checked of 31.8 to 64.8 with *Mac* and *Van*, respectively. For combinations missed they show an average of 5.5 to 30.6[3], with *Tho* and *How*, respectively. Their normal group averages are 52.3 and 14.0. The low-diet group averages of the same squad are 67.4 and 12.7, indicating improvement during the reduced diet.

For purposes of comparison, it is desirable to state the results in one figure which will stand as a combination of speed and accuracy. The subjects worked with a time limit, and equal stress was laid on checking the largest number of combinations, and also on going over the material without missing any combinations. The latter was frequently called to the subject's attention first to give it prominence; still it is likely that the matter of speed was more prominent in the thoughts of the subject. In computing the combination value, which is given in tables 153 and 154, a credit of +1 was allowed for each correct number combination found and checked. A demerit of −0.5 was subtracted for every error of omission and for every wrong combination checked. On this basis the scores range from 6.5 (*Spe*, September 29) to 113 (*Vea*, February 2) with Squad A and from −6.5 (*Sch*, January 19) to 99 (*Van*, January 27) in the case of Squad B. In Squad A of the 10 men for whom there are complete records the best number-cancellation scores were made by *Vea*, *Pea*, *Gul*, and *Bro*. These low-diet averages, as seen in the lower line of table 153, are respectively: 88.8, 78.7, 76.2 and 73.8. With the exception of *Gar*, all of the subjects improved on their first low-diet date, although *Moy* and *Tom* did but very little better on October 13 than they had on September 29. Throughout the whole experiment each individual improved

[1] *Can* frequently complained of his eyes during these tests. Part of the time he wore an eye-shield during the group experiment. He complained that the light was too strong and he frequently said in the evening that he had a headache. He was asked repeatedly to have his eyes re-examined by a good specialist.

[2] *Spe*, who did not have so much practice as the others, had a lower average, *i. e.*, 36.2.

[3] The data for *Sch* are too fragmentary for comparison.

quite regularly in the performance of his test. *Gul* shows a marked drop in his score for January 12, with a surprising number of omissions, which were more than the correct combinations checked. On the two previous dates his score was about 100 and on the two succeeding dates it was above 100. Two other subjects, *Mon* and *Pec*, were also lower on January 12, the first session following the Christmas vacation. Almost a month had elapsed since the preceding experiment; moreover the men were undergoing a very considerable reduction in diet at this time.

TABLE 152.—*Squad B—Cancellation of specified number groups.*

Date and number groups.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.[1]
1917.															
Oct. 6:															
Found	22	23	24	21	....	....	27	21	....	17	22	25	29	33	24.3
Missed	24	7	25	30	....	....	3	27	....	14	8	3	13	3	13.0
Mistakes	0	0	0	0	....	....	0	0	....	1	2	0	0	1	.4
Nov. 3:															
Found	42	47	48	53	34	....	58	29	....	45	44	46	61	62	50.6
Missed	28	7	40	14	20	....	13	27	....	4	17	9	10	8	15.0
Mistakes	0	0	1	0	0	....	1	0	....	0	0	1	0	0	.3
Nov. 17:															
Found	52	56	58	61	45	....	56	36	....	52	65	54	69	72	59.5
Missed	20	10	29	5	21	....	17	34	....	6	16	6	12	8	12.9
Mistakes	0	0	0	0	0	....	0	0	....	0	0	0	0	0	0
Dec. 15:															
Found	....	57	55	57	40	....	60	41	....	61	55	59	80	69	61.4
Missed	....	9	29	13	29	....	12	28	....	11	16	4	25	11	14.4
Mistakes	....	0	0	1	1	....	0	1	....	0	0	0	0	0	.1
1918.															
Jan. 5:															
Found	51	64	64	56	46	35	....	....	40	63	67	....	85	74	65.5
Missed	17	13	30	12	28	13	....	....	59	6	9	....	24	5	14.5
Mistakes	0	0	0	1	0	1	....	....	0	2	0	....	0	0	.4
Normal av.:															
Found	40.5	49.4	49.8	49.6	41.3	35.0	50.3	31.8	40.0	47.6	50.6	46.0	64.8	62.0	52.3
Missed	22.3	9.2	30.6	14.8	24.5	13.0	11.3	29.0	59.0	8.2	13.2	5.5	16.8	7.0	14.0
Mistakes	0	0	.2	.4	.3	1.0	.3	.3	0	.6	.4	.3	0	.2	.2
Jan. 13:															
Found	53	71	66	71	....	47	59	....	41	64	63	57	89	68	66.1
Missed	13	14	22	6	....	11	12	....	47	9	8	9	20	11	12.4
Mistakes	0	0	0	0	....	0	0	....	0	0	0	1	0	0	.1
Jan. 19:															
Found	53	74	59	61	....	49	66	....	33	68	66	53	80	74	65.4
Missed	9	14	29	13	....	10	6	....	79	4	22	9	16	14	13.6
Mistakes	1	0	0	0	....	0	0	....	0	0	0	0	0	0	.1
Jan. 27:															
Found	59	86	58	65	....	55	67	....	60	76	55	61	104	75	70.6
Missed	12	18	32	14	....	19	4	....	90	7	3	11	10	11	12.2
Mistakes	0	0	0	0	....	0	0	....	2	0	0	0	0	0	0
Low-diet av.:															
Found	55.0	77.0	61.0	65.7	....	50.3	64.0	....	44.7	69.3	61.3	57.0	71.0	72.3	67.4
Missed	11.3	15.3	27.7	11.0	....	13.3	7.3	....	72.0	6.7	11.0	9.7	15.3	12.0	12.7
Mistakes	.3	0	0	0	....	0	0	....	0	0	0	.3	0	.3	.07

[1] These averages do not include the records of *McM*, *Kim*, *Mac*, and *Sch*.

The average for the 10 regular subjects of Squad A (see right-hand column of table 153) shows a rapid and uninterrupted improvement except on January 12.

Squad B, table 154, shows the same general result with this test. In the five normal experiments all the subjects improved regularly, with the exception of a small relapse on the part of some subjects, for example, *How*, *Ham*, *McM*, *Sne* and *Wil* on December 15. In the normal averages *Wil* and *Van* lead with scores of 58.4 and 55.4, respectively.

TABLE 153.—*Squad A—Efficiency scores for cancellation of number groups.*

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom	Ves.	Fre.	Av.
Sept. 29	24	17.5	21.5	25.5	31.5	27.5	23	40	17.5	6.5	37.5	34	29	27.8
Oct. 13	49	24	....	13	44	55	27	50	31	25.5	39	64	44.5	39.6
Oct. 27	62	45	36.5	54.5	64	61.5	46.5	67.5	48	38	43.5	73	....	5[illegible].6
Nov. 10	62	52	53.5	59	63	73.5	36	81	41.5	28	48	73.5	....	59.0
Nov. 24	73.5	57	60.5	62	65	60.5	27.5	87	51	32	49.5	97	....	63.0
Dec. 8	78.5	63	61.5	62	109	57	53.5	78.5	61.5	40.5	54	83	....	70.0
Dec. 19	78	66.5	66	65	98.5	64.5	42	80	58	....	53.5	95	....	70.1
Jan. 12	77	62.5	63.5	69.5	35	52.5	49	69.5	49.5	....	53	101.5	....	61.9
Jan. 26	87	68	66	70.5	102	66	51	97	58.5	....	54	99.5	....	75.4
Feb. 2	97	64	75	75.5	105.5	72	66	98	66.5	....	66.5	113	....	82.4
Low-diet average	73.8	55.8	60.3	59.0	76.2	62.5	44.3	78.7	51.7	32.8	51.2	88.8	44.5	64.2

TABLE 154.—*Squad B—Efficiency scores for cancellation of number groups.*

Date.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
Oct. 6	10	19.5	11.5	6	....	....	25.5	7.5	....	9.5	17	23.5	22.5	31	17.6
Nov. 3	28	43.5	27.5	46	24	....	51	15.5	....	43	35.5	36	51	58	42.0
Nov. 17	42	51	43.5	58.5	34.5	....	47.5	19	....	49	57	51	63	68	53.1
Dec. 15	....	52.5	40.5	50	25	....	54	26.5	....	55.5	47	57	67.5	63.5	54.1
Jan. 5	42.5	57.5	49	49.5	32	28	....	....	10.5	59	62.5	....	73	71.5	58.0
Normal av.	30.6	44.8	34.4	42.0	28.9	28.0	44.5	17.1	10.5	43.2	43.8	41.9	55.4	58.4	45.0
Jan. 13	46.5	64	55	68	....	41.5	53	....	17.5	59.5	59	47	79	62.5	59.4
Jan. 19	43	67	44.5	54.5	....	39	63	....	−6.5	66	55	48.5	72	67	58.1
Jan. 27	53	77	42	58	....	45.5	65	....	15	72.5	53.5	55.5	99	69.5	64.5
Low-diet av.	47.5	69.3	47.2	60.2	....	42.0	60.3	....	6.7	66.0	55.8	50.3	83.3	66.3	60.7

tively. Several subjects have scores of 40 and above. These in order of rank would be *Har*, *Lon*, *Sne*, *Liv*, *Ham*, and *Tho*. In the low-diet period each subject for whom records are complete shows an average above his normal. In the case of *Sch*, who only had one normal experiment (January 5) there was no improvement and, in fact, a slight decrement during the reduction period. This subject omitted a large number. (See record for January 27.) In the low-diet period the highest average was that of *Van*, 83.3, an increase of 27.9

over his normal average. Two other subjects, *Har* and *Liv*, made increases above 20, but on the average the improvement during the 3 weeks of the reduced diet was small, there being hardly any on January 13 and 19.

The general averages for the two squads are plotted in figure 104. The main interruption in the improvement shown by Squad A was on January 12, as previously mentioned. Considering the points from which the two squads start, each improved approximately the same amount. The curves are regular and of the usual practice form. It will be noted that Squad A, on their one normal date, were at a higher level than Squad B, the difference being 10 points in favor of Squad A.

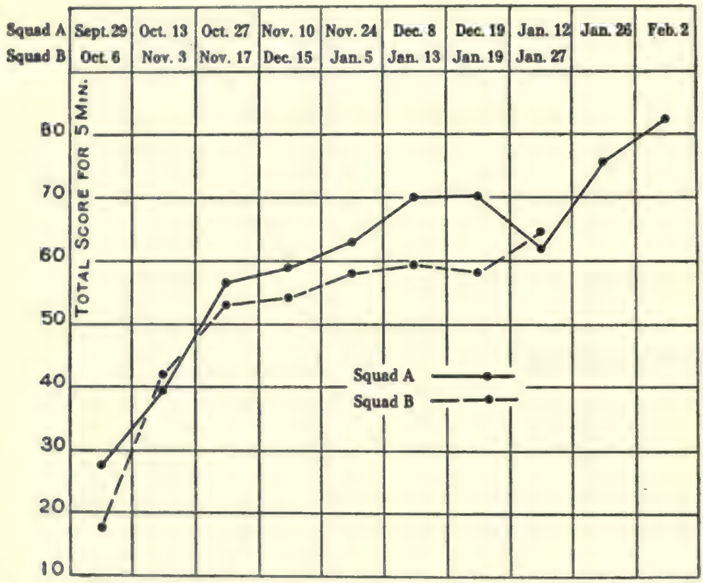

FIG. 104.—Efficiency in the cancellation of specified number-groups.

In the two succeeding experiments, however, which were during reduced diet, Squad A failed to maintain this advantage and improved relatively slower than Squad B. During the low-diet period, Squad B also made but a minor improvement, almost all of which was on the last date. It appears, therefore, from the data at hand, that improvement in efficiency for quickly and accurately locating and cancelling desired number combinations in heterogeneous material is not favored by the condition of reduced diet.

(4) ADDITION OF ONE-PLACE NUMBERS.

In an adding experiment when a time limit is used and the units in the task are as large as those employed here, that is, columns of 10 digits each, in which each column is added and the sum recorded separately, it must inevitably happen that when the signal to stop

is given, some subjects will have a column only partly added. Obviously they can not be allowed to complete the column. The possibility of having the subject draw a mark through the column and write down the sum to that point, was considered. It seemed, however, that this would introduce the possibility of much irregularity and that as the time limit allowed for the task was 10 full minutes without interruption, it would be better to sacrifice this fraction of achievement in favor of a more simple and concise method of procedure. On the average, over 50 columns were correctly added during the 10-minute interval. The average loss could thus be not more than 2 per cent.

In the oft-repeated instructions, which always preceded the addition experiment, the matter of accuracy was given much more prominence than speed. The men were made to understand definitely that a column added incorrectly had better not have been added at all, so far as the score of the subject was concerned. In tables 155 and 156, which are of the usual form, the data presented give first place to accurate work. Two values are entered for each subject: (1) the number of columns of 10 digits *correctly* added during the 10-minute interval, and (2) the percentage of the total number of added columns whose sums were incorrect. For illustration, *Bro* of Squad A on September 29 added a total of 50 columns. Of these, 8 were incorrectly added. He therefore has a score on that date, as shown in table 155, of 42 columns correct and 16 per cent of errors. *Can* on the same date added a total of 30 columns, of which 6 were in error. His score is consequently 24 and 20 for correct columns and per cent error, respectively. To convert the errors into per cent makes possible the more direct comparison between subjects. The total number of columns added, if desired, may be computed from the two values in each of tables 155 and 156. For example, if the score for columns correct is 42 and the per cent of errors is 16, then 42 is 84 per cent of the total columns.

The individual variations among the members of Squad A are shown in the low-diet averages in table 155. *Fre*, *Tom*, and *Pea* average the largest number of correct columns in the time limit, with the values of 76.0, 61.8, and 58.3. Subject *Fre* was a remarkably good adder, but his case is of little interest to us, since he did not remain in the squad and the data are very few. Of the other men, the two previously mentioned (*Tom* and *Pea*) were at the head of the group in the normal experiment on September 29. In small percentage of errors these men do not lead, however, in the average during the low-diet period. *Bro* and *Gar*, with 4.3 and 8.0 per cent, have somewhat the advantage. *Bro* on October 13 and *Pea* on January 26 showed the only instances in which the subject's entire performance was without error. While there is considerable fluctuation in an indi-

TABLE 155.—*Squad A—Results in 10-minute addition test.*

Date.	Columns.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.
Sept. 29......	Correct.....	42	24	30	34	33	46	25	51	33	10	56	31	86	37.5
	P. ct. errors.	16.0	20.0	14.3	15.0	25.0	14.8	41.9	15.0	31.3	54.6	9.7	26.2	10.4	21.5
Oct. 13......	Correct.....	48	27	....	35	38	51	34	53	35	20	56	34	76	41.1
	P. ct. errors.	0.0	10.0	....	2.8	22.4	16.4	26.1	13.1	40.7	28.6	13.8	27.7	5.0	17.3
Oct. 27......	Correct.....	49	22	33	33	40	43	31	58	53	17	57	36	....	42.2
	P. ct. errors.	3.9	33.3	15.4	15.4	24.5	18.9	35.4	10.8	11.7	37.0	10.9	25.0	....	19.0
Nov. 10......	Correct.....	46	29	36	38	45	42	38	56	49	22	64	45	....	45.2
	P. ct. errors.	4.2	17.2	12.2	11.6	25.0	26.3	20.8	16.4	19.7	26.6	8.6	11.8	....	16.2
Nov. 24......	Correct.....	47	21	35	36	49	46	39	60	50	13	61	40	....	44.9
	P. ct. errors.	6.0	27.6	18.6	12.2	18.3	13.2	20.4	14.3	12.3	51.8	14.1	13.0	....	15.1
Dec. 8......	Correct.....	50	22	36	33	49	45	32	54	54	22	64	36	....	43.9
	P. ct. errors.	3.8	24.2	16.3	5.7	21.0	16.7	36.0	10.0	19.4	31.2	9.9	23.4	....	17.0
Dec. 19......	Correct.....	50	27	36	38	48	46	34	55	63	....	64	38	....	46.3
	P. ct. errors.	5.7	15.6	14.3	2.6	23.8	16.4	37.0	14.1	13.7	....	9.9	22.4	....	16.1
Jan. 12......	Correct.....	49	27	37	32	52	47	27	56	61	....	59	45	....	45.5
	P. ct. errors.	2.0	12.9	7.5	11.1	21.2	16.0	37.2	8.2	10.3	....	7.8	15.1	....	14.2
Jan. 26......	Correct.....	48	24	39	32	57	47	41	66	48	....	65	38	....	46.6
	P. ct. errors.	7.7	22.6	13.3	5.9	12.3	7.8	21.2	0.0	25.0	....	7.1	22.4	....	13.2
Feb. 2......	Correct.....	51	29	42	39	62	45	43	67	55	....	66	45	....	50.2
	P. ct. errors.	5.6	19.4	10.6	4.9	12.7	15.1	14.0	6.9	20.3	....	8.3	10.0	....	11.7
Low-diet av...	Correct.....	48.7	25.3	36.8	35.1	48.9	45.8	35.4	58.3	52.0	18.8	61.8	39.7	76.0	45.1
	P. ct. errors.	4.3	20.3	13.5	8.0	20.1	16.3	27.6	10.4	19.2	35.0	10.0	19.0	5.0	15.5

TABLE 156.—*Squad B—Results in 10-minute addition test.*

Date.	Columns.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
Oct. 6..	Correct.....	27	19	61	33	....	....	42	43	....	22	27	80	33	49	39.3
	P. ct. errors.	18.2	29.6	7.6	15.4	....	....	26.3	6.5	....	31.2	32.5	3.6	15.4	17.0	19.7
Nov. 3..	Correct.....	31	24	69	36	13	....	41	51	....	25	33	86	28	47	42.0
	P. ct. errors.	3.0	4.0	9.2	14.3	41.0	....	10.9	5.6	....	16.7	8.3	5.5	22.2	14.5	10.9
Nov. 17..	Correct.....	34	23	76	37	14	....	48	55	....	31	30	91	37	43	45.0
	P. ct. errors.	0.0	11.5	1.3	7.5	51.7	....	14.3	0.0	....	3.1	9.1	7.1	9.8	14.0	7.8
Dec. 15..	Correct.....	....	24	67	31	16	....	45	54	....	29	35	86	42	41	44.4
	P. ct. errors.	....	4.0	6.9	24.4	51.5	....	6.3	8.4	....	12.1	7.9	3.4	8.7	24.0	10.8
Jan. 5..	Correct.....	35	23	71	38	16	39	....	....	9	26	29	....	44	43	38.6
	P. ct. errors.	7.9	14.8	10.1	7.3	36.0	13.3	....	....	62.5	13.3	14.7	....	0.0	8.5	9.6
Normal av.....	Correct.....	31.8	22.6	68.8	23.0	14.8	39.0	44.0	50.8	9.0	26.6	30.8	85.8	36.8	44.6	41.9
	P. ct. errors.	7.3	12.8	7.0	13.8	45.1	13.3	14.5	5.1	62.5	15.3	14.5	4.9	11.2	15.6	11.8
Jan. 13..	Correct.....	33	18	68	31	....	38	32	....	14	24	36	79	41	48	41.0
	P. ct. errors.	10.8	28.0	6.9	18.4	....	9.5	23.8	....	44.0	14.3	5.3	10.2	10.9	11.1	14.0
Jan. 19..	Correct.....	38	22	73	30	....	36	42	....	22	28	30	96	36	42	43.7
	P. ct. errors.	9.5	4.4	8.8	14.3	....	16.3	14.3	....	29.0	15.2	9.1	6.8	12.2	12.5	10.7
Jan. 27..	Correct.....	32	25	72	46	....	36	43	....	21	24	33	103	44	49	47.1
	P. ct. errors.	20.0	7.4	6.5	9.8	....	14.3	6.5	....	30.0	7.7	10.8	1.9	4.3	12.5	8.7
Low-diet av.....	Correct.....	34.3	21.7	71.0	35.7	....	36.7	39.0	....	19.0	25.3	33.0	92.7	40.3	46.3	43.9
	P. ct. errors.	13.4	13.3	7.4	14.2	....	13.4	14.9	....	34.3	12.4	8.4	6.3	9.1	12.0	11.1

vidual's record from experiment to experiment, yet in general this is not such as to make it apparent that one individual influences predominantly the average for any one date. Five of the subjects whose records enter into the final averages for the squad, that is, *Can, Gul, Moy, Pec,* and *Vea,* have average low-diet errors of 19 per cent or above. Not one of these 5 subjects on any of the 9 dates which fell within the reduction period has a percentage of error less than 10 per cent. The largest is for *Pec* on October 13, viz, 40.7 per cent. This is somewhat compensated in the average by the fact that *Moy* on the same date had 26.1 per cent, which was a little below the average for him during the first part of the experiment. The errors for *Gul* were large, but during the greater part of the experiment they were quite consistent. Beginning with September 29 they are, in order, 25.0, 22.4, 24.5, 25.0, 18.3, 21.0, 23.8, 21.2, 12.3, and 12.7 per cent. The average score for Squad A during the whole of the reduction period, as shown at the bottom of the right-hand column in table 155, is 45.1 columns correct, with 15.5 per cent of errors.

In the case of Squad B the normal average performance shows that the individuals who made up this squad demonstrated a larger average variability than was found in Squad A. The scores for columns correctly added range from 85.8 and 68.8 for *Tho* and *How*, respectively, to 14.8 and 9.0 for *McM* and *Sch*. The data for the last two subjects are only fragmentary, as was also the case with *Spe* of Squad A. Nevertheless, there is somewhat more variability in Squad B, since no one in Squad A did so well as *Tho* and *How* of the former, and moreover, the scores of *Har* and *Ham* (22.6 and 23.0), both of Squad B, are slightly smaller than the smallest score with Squad A, *i. e., Can,* 25.3.[1] The average normal performance for Squad B is 41.9 correct columns—about 3 columns less than the low-diet average of Squad A.

In the matter of percentage of errors, with the exception of *Sch* and *McM*, whose data, particularly those of the former, have been mentioned as incomplete and do not enter into the average for Squad B, the values are in general in the same range as those found for Squad A. The final normal average of 11.8 per cent for Squad B is 3.7 per cent less than that found for Squad A. It is noteworthy that the two subjects of Squad B, who lead with the largest number of columns correctly added, are also in the lead in the smallest percentage of errors of any of the 10 subjects from whom the final squad average is drawn. In comparing Squad B's normal average with the average for the three reduced-diet dates, only minor fluctuations are noted. Seven of the 10 subjects show increase in the number of columns correctly added. Only 4 showed a reduction in the percentage of errors. The final average for this period shows an increase of 2 columns in the 10 minutes, *i. e.,* 43.9 compared to 41.9, and a decrease of 0.7 per cent in errors, 11.8 to 11.1 per cent.

[1]This comparison is among the 10 regular subjects of each squad.

The results are compared directly in figure 105. The performance of each squad is represented by three curves: (1) total number of columns added in 10 minutes; (2) number of columns correctly added in 10 minutes; and (3) percentage of errors in the total number of columns added. In the case of the total number of columns both squads began at identically the same level. Squad A shows a rather smooth and gradual practice curve, with the exception of the points at November 10 and February 2. On the latter date evidently special effort was made. Squad B does not show so much improvement. The second session was slightly below the record of the first, but it must be recalled that the time interval elapsing was 1 month. At January 5 there is a distinct drop. This was apparently caused in largest part by the absence of subject *Tho*, the champion adder of the squad, who had been a bank clerk. *Tho*, because of transportation

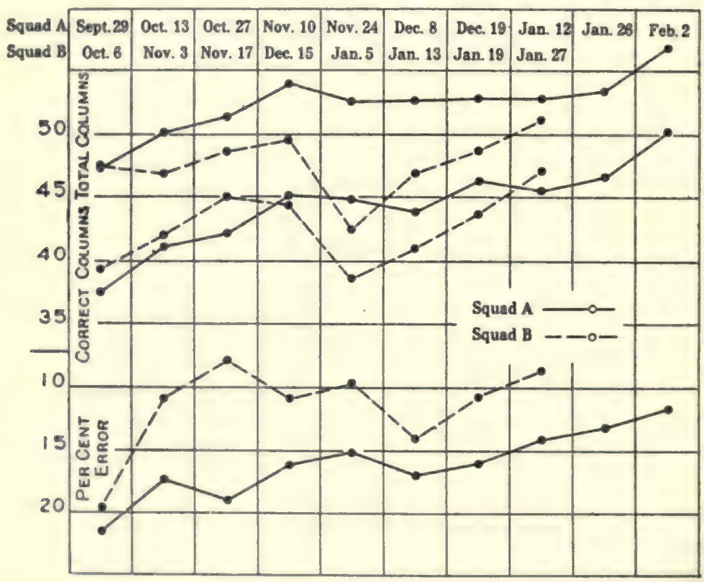

FIG. 105.—Average results in the 10-minute addition test.

difficulties in returning from the Christmas vacation, was unable to reach the Laboratory on this evening until the group work had been completed. Squad B also reached their highest point on the last date, January 27. The two preceding dates for this squad, January 13 and 19, both of which were in the reduced-diet period, were not up to the level that would have been expected on the basis of the performance for December 15 and previously. The whole squad was present on January 13 and 19. One would therefore normally expect some increase over previous experiments. The fact that there was none may reasonably be charged to the low-diet conditions.

The factor of accuracy entered into the second set of curves, showing the number of columns correctly added. There is a reversal in the first three sessions in this case, Squad B showing the better score. The two squads are very nearly equal at their fourth session. At the fifth session, Squad B was handicapped by the absence of *Tho.* In the sixth and seventh sessions they again show a poorer performance than would have been expected on the basis of their previous experience and records. On the last date they rallied, with a performance on the average two columns better than anything they had previously done. The curve for Squad A is fairly regular; there is a very slight decline in the fifth and sixth sessions as compared to the fourth, and in the eighth session as compared with the seventh, but these do not seem large enough to be of much significance. The curve is below that for Squad B during the first three sessions, including the normal of September 29.

In the percentage of errors the two squads differ widely. Although they began fairly near the same point, Squad A at 21.5 per cent and Squad B at 19.7 per cent, the distance between them becomes prominent in the next two experiments. It is also large in the fourth and fifth sessions. In the sixth for Squad B, which was their first during the low-diet period, they show a definite decline. There is some recovery in the seventh session, *i. e.*, the second low-diet session, but the level reached is not what would be expected on the basis of their previous records. On the last date, even though there was some tendency to a spurt of unusual effort, they did not reach a level exceeding that which had previously been reached. The fact that the two squads began at almost the same level of errors, and that in the second, third, fourth, and fifth sessions Squad A did not make nearly so much improvement as Squad B, coupled with the fact that Squad B at the beginning of the reduced diet showed an increase in the percentage of error,[1] makes it appear that the reduction in diet was not favorable to the highest possible performance in accurate work in intensive adding during a period of 10 minutes of continuous test.

(5) MEMORY SPAN FOR 4-LETTER ENGLISH WORDS.

When the subjects tried to recall and record as many as possible of the 25 monosyllable English words which were read for the memory-span test, nothing was said about what would be done in the case of words entered which were not pronounced. In a few instances, several words having nearly the same sound were entered, showing that the subject evidently remembered the general sound complex of the word, but was not absolutely sure as to its identity. In these special cases the extra words entered were not counted as errors. In tables 157

[1]It should be noted that this increase in the percentage of error does not occur on January 5, when there is a drop in the curve above, and is not due to the absence of any one man, since the whole personnel of the squad was present on this and on the other low-diet dates.

and 158, opposite the different dates and under the different subjects, will be found the number of words correctly entered and also the

TABLE 157.—*Squad A—Memory span for 4-letter English words.*

Date.	Words.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.
1917. Sept. 29..	Correct..	7	5	6	4	6	6	4	10	7	7	10	8	6	6.7
	Errors...	0	1	3	3	3	2	3	1	1	1	0	1	3	1.5
Oct. 13..	Correct..	11	6	....	12	7	6	6	11	9	9	12	5	12	8.5
	Errors...	0	0	....	1	0	3	1	0	2	0	1	3	2	1.1
Oct. 27..	Correct..	9	5	7	7	9	5	8	10	6	9	10	5	....	7.4
	Errors...	1	0	2	3	0	3	2	2	1	1	1	5	....	1.8
Nov. 10..	Correct..	11	7	6	8	7	5	11	6	5	10	11	9	....	8.0
	Errors...	0	0	1	1	2	2	0	3	2	2	1	0	....	1.1
Nov. 24..	Correct..	10	7	4	9	8	4	10	6	7	10	9	7	....	7.7
	Errors...	1	1	3	1	2	7	1	2	0	0	1	2	....	1.8
Dec. 8..	Correct..	9	10	5	9	7	7	8	8	8	8	13	4	....	8.3
	Errors...	0	2	3	0	0	1	2	0	0	0	1	3	....	0.9
Dec. 19..	Correct..	10	7	7	10	6	7	10	9	8	....	15	7	....	8.9
	Errors...	1	1	1	2	1	2	0	2	2	....	1	0	....	1.2
1918. Jan. 12..	Correct..	8	8	9	11	7	4	10	10	9	....	12	7	....	8.6
	Errors...	1	1	0	0	0	4	0	1	0	....	1	0	....	0.8
Jan. 26..	Correct..	10	10	6	9	9	7	11	9	8	....	14	7	....	9.4
	Errors...	0	0	1	1	1	4	1	0	1	....	0	0	....	0.8
Feb. 2..	Correct..	10	7	12	9	8	8	13	9	7	....	13	7	....	9.1
	Errors...	0	0	0	2	2	1	0	2	0	....	0	1	....	0.8
Low-diet av.	Correct..	9.8	7.5	7.0	9.3	7.6	5.9	9.7	8.7	7.4	9.2	12.1	6.4	12.0	8.4
	Errors...	0.4	0.6	1.4	1.2	0.9	3.0	0.9	1.3	0.9	0.6	0.8	1.6	2.5	1.1

TABLE 158.—*Squad B—Memory span for 4-letter English words.*

Date.	Words.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917. Oct. 6	Correct.	7	5	5	7	....	....	13	10	....	7	3	7	7	12	7.3
	Errors..	1	2	3	1	....	....	1	0	....	1	2	0	0	1	1.2
Nov. 3	Correct.	7	8	10	10	6	....	13	11	....	6	7	6	10	10	8.7
	Errors..	1	2	1	0	0	....	0	0	....	0	0	0	1	2	0.7
Nov. 17	Correct.	8	9	4	8	6	....	10	12	....	9	5	9	7	12	8.1
	Errors..	1	0	3	0	1	....	0	0	....	0	1	0	1	4	1.0
Dec. 15	Correct.	....	6	6	7	6	....	8	11	....	8	9	9	7	9	7.7
	Errors..	....	1	1	1	1	....	0	0	....	0	0	0	3	2	0.9
1918. Jan. 5	Correct.	8	6	10	8	5	7	....	....	6	9	8	....	10	13	9.0
	Errors..	0	1	1	0	1	2	....	....	0	1	1	....	0	3	0.9
Normal av.	Correct.	7.5	6.8	7.0	8.0	5.8	7	11.0	11.0	6	9.8	6.4	7.8	8.2	11.2	8.2
	Errors..	0.8	1.2	1.8	0.4	0.8	2	0.3	0	0	0.4	0.8	0	1	2.4	0.9
Jan. 13	Correct.	10	9	5	8	....	9	12	....	6	8	8	10	9	11	9.0
	Errors..	1	0	1	0	....	1	0	....	4	1	1	0	0	2	0.6
Jan. 19	Correct.	7	6	7	8	....	7	14	....	7	5	7	7	7	9	7.7
	Errors..	0	0	1	0	....	2	0	....	3	1	0	0	2	2	0.6
Jan. 27	Correct.	6	9	7	12	....	9	12	....	7	6	6	9	8	8	8.3
	Errors..	2	1	1	0	....	0	1	....	4	0	1	0	0	4	1.0
Low-diet av.	Correct.	7.7	8.0	6.3	9.3	....	8.3	12.7	....	6.7	6.3	7.0	8.7	8.0	9.3	8.3
	Errors..	1.0	0.3	1.0	0.0	....	1.0	0.3	....	3.7	0.7	0.7	0.0	0.7	2.7	0.7

number of wrong words given. From the general average figure in the lower right-hand corner of tables 157 and 158 it will be seen that the usual score is a fraction over 8 words correctly remembered and recorded from the list of 25 pronounced, and on the average 1 wrong word is entered. The average performance is very nearly the same with both squads. With these figures in mind, the comparison of the individual subjects in their memory span shows for Squad A that the average number of correct words ranged from 5.9 to 12.1 (*Mon* and *Tom*) and the average number of errors from 3.0 to 0.4 (*Mon* and *Bro*). There were many individual records which ranged about 8 or above with no errors. The highest of these was *Tom* of January 26, with 14 correct words and no errors. The largest number of errors was made by *Mon* on November 24; there were 4 correct words and 7 wrong ones entered at that time. There is a fair amount of uniformity in the records of the individual subjects. A subject may show a variation of 2 on either side of his average number of correct words.

Squad B gives about the same range of memory span as Squad A. The averages of the 5 normal sessions range from 5.8 to 11.2 for words correctly remembered. In these 5 experiments the subjects had not received so much practice in the test as had Squad A, and the fact that the average is slightly below that for the latter group can not be regarded as at all significant. The number of errors was somewhat less with Squad B. Two of the subjects, *Tho* and *Mac*, made no error in any trial. This was a very good record, considering that in the case of *Mac* the number of words correctly remembered was above the average of these squads. *Lon* made a very good memory record; his average for correct words for the normal period is 11.0 and for the reduced-diet period 12.7. Only 2 errors were made in the 7 sessions in which he served—one on October 6 and one on January 27. Another subject, *Ham*, should be mentioned in this connection as having made only 2 errors, both during the normal period, 1 each on October 6 and December 15.

The data seem homogeneous, and no violence appears to be done by converting a subject's record, as shown in the number of words correctly recalled and the number of errors made into one score. This has been done very arbitrarily by deducting the number of errors from the number of words correctly remembered. The scores thus computed are given in tables 159 and 160. This simplification makes no especial change in the standing of the subjects in the groups. The average low-diet scores range from 2.9 to 11.3 for *Mon* and *Tom*, respectively. *Bro* and *Moy* also have large averages, viz, 9.3 and 8.9. The average score for all subjects in all sessions during the low diet is 7.3. Squad B shows a range of variability from 3.0 to 12.3. This group is led by *Lon* with a score for normal of 10.8 and a low-diet average of 12.3. The general averages for the group of 10 individuals in all sessions is 7.2 for

the normal and 7.6 for the low diet. With the exception of *Liv*, *Wil*, and *Fis*, all the 10 regular subjects show better scores for the low-diet period than during the normal sessions, that is, the improvement continued during the reduction in diet.

The relation between the scores of the two groups and the food reduction period is brought out best in figure 106. Both curves show a tendency to improvement; Squad B is somewhat above A at the beginning and in four of the other sessions. In the fourth session they

TABLE 159.—*Squad A—Memory score.*

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.
Sept. 29	7	4	3	1	3	4	1	9	6	6	10	7	3	5.2
Oct. 13	11	6	....	11	7	3	5	11	7	9	11	2	10	7.4
Oct. 27	8	5	5	4	9	2	6	8	5	8	9	0	....	5.6
Nov. 10	11	7	5	7	5	3	11	3	3	8	10	9	....	6.9
Nov. 24	9	6	1	8	6	−3	9	4	7	10	8	5	....	5.9
Dec. 8	9	8	2	9	7	6	6	8	8	8	12	1	....	7.4
Dec. 19	9	6	6	8	5	5	10	7	6	....	14	7	....	7.7
Jan. 12	7	7	9	11	7	0	10	9	9	....	11	7	....	7.8
Jan. 26	10	10	5	8	8	3	10	9	7	....	14	7	....	8.6
Feb. 2	10	7	12	7	6	7	13	7	7	....	13	6	....	8.3
Low-diet average	9.3	6.9	5.6	8.1	6.7	2.9	8.9	7.3	6.6	8.6	11.3	4.9	10	7.3

TABLE 160.—*Squad B—Memory score.*

Date.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
Oct. 6	6	3	2	6	....	....	12	10	....	6	1	7	7	11	6.1
Nov. 3	6	6	9	10	6	....	13	11	....	6	7	6	9	8	8.0
Nov. 17	7	9	1	8	5	....	10	12	....	9	4	9	6	8	7.1
Dec. 15	....	5	5	6	5	....	8	11	....	8	9	9	4	7	6.8
Jan. 5	8	5	9	8	4	5	....	....	6	8	7	....	10	10	8.1
Normal average	6.8	5.6	5.2	7.6	5.0	5	10.8	11.0	6.0	7.4	5.6	7.8	7.2	8.8	7.2
Jan. 13	9	9	4	8	....	8	12	....	2	7	7	10	9	9	8.4
Jan. 19	7	6	6	8	....	5	14	....	4	4	7	7	5	7	7.1
Jan. 27	4	8	6	12	....	9	11	....	3	6	5	9	8	4	7.3
Low-diet av.	6.7	7.7	5.3	9.3	....	7.3	12.3	....	3.0	5.7	6.3	8.7	7.3	6.7	7.6

were at about the same level; in the seventh and eighth sessions Squad B dropped below. The fluctuations are rather large with both squads. Squad B shows a falling off on November 17 and December 15, but good results on January 5, *i. e.*, just after the vacation, a date that shows poorly in several measurements. On January 13, their first low-diet session, they have the best average of the whole experiment in marked contrast to low-diet dates January 19 and January 27. Squad A demonstrates a large amount of variability in the early part of the

investigation. The second session, as with B, showed great improvement over the first and the two squads came nearer to the same level. The average for the next three sessions is low. From December 8 to the end of the experiment, A showed consistent improvement, with relatively small changes from session to session.

The reduced diet can not be considered as favoring better scores than normal in the memory-span experiment. The decrease in the last two sessions with B and the poor scores in the third and fifth sessions for A seem in the direction of a low-diet effect. On the other hand, B, with no assigned reason, except that they did not receive so frequent practice as A, showed a marked decrease in the third and fourth sessions. Had they at these points kept up their

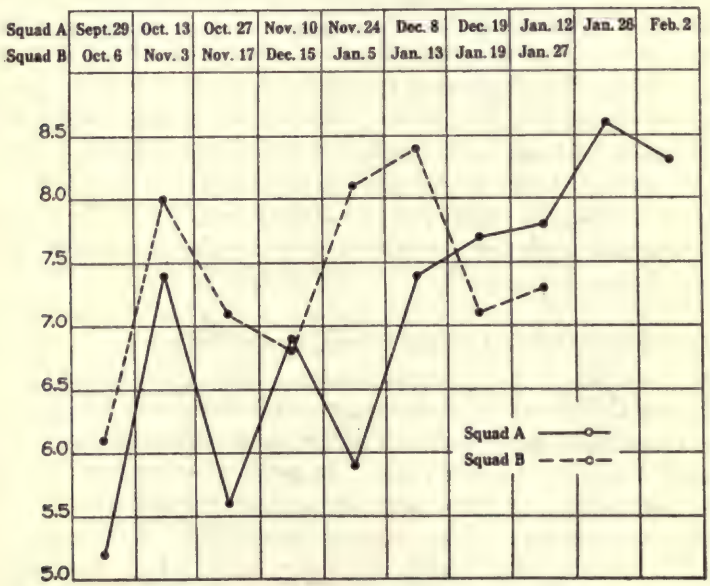

Fig. 106.—Average scores for memory span.

level of November 3 and January 5, Squad A would by contrast have made a poor record in the early part of the experiment, and B would have appeared to decline in the second and third experiments with food reduction. Our conclusions from the memory-span results can not be positive on account of the apparently large normal fluctuations in practice. It seems safest to believe that the reduced diet produced no certain change.

THE INDIVIDUAL PSYCHOLOGICAL MEASUREMENTS.

(6) STRENGTH OF GRIP.

It was the original plan in this investigation that strength and endurance tests should be given to the members of the squads from time to time in the gymnasium at Springfield. Circumstances over which

we had no control interfered and this part of the plan failed to materialize. Strength of grip was therefore made a part of the psychological program to help offset this deficiency. There are no records for the normal session of Squad A, *i. e.*, for September 29, with which the later ones may be compared. The results from tests made in the evening are given in tables 161 and 162 and entered separately for right and left hands. Five trials were made alternately with each hand, the figure given being the average of the five in kilograms. For each average there is a standard deviation and coefficient of variability.

In the evening records of Squad A (table 161), October 27 to February 2, inclusive, are during the low-diet period. As would be expected, the total individual averages are higher for the right hand than for the left.[1] The average for the right is 48.1 and for the left, 44.7, with a difference of about 3.5 kg. The individuals are very closely grouped. For the right hand the range is from 56.6 (*Gul*) to 41.6 kg. (*Pea*). The last-mentioned subject was left-handed. *Kon* shows almost equally good scores for both his hands. His record for the left hand of 54.8 kg. is the highest for the squad; the lowest average record with the left hand is 36.0 kg. for *Mon*. Five trials is not a large number from which to compute variability, but with the strength of grip test it is not desirable to take a large number of trials, since the element of fatigue soon enters as a prominent factor.

As explained in the section on method (page 150), the trials were separated by suitable intervals to minimize fatigue and to secure as nearly as possible an even performance. The general success of this can be judged definitely by the average coefficients of variability shown in the extreme right-hand column of the table with the other averages; these range from 3 to 6 per cent. Inspection of the table will show that the individual subjects were remarkably consistent in showing this small variability. The largest variability was with *Pea* on January 12 for the right hand—18.3 per cent. For this there is an explanation in that the subject had a sprained wrist which pained him when he used his full strength.

Squad B (table 162) showed averages higher than those of Squad A. The general averages for the four normal experiments are 55.1 kg. for the right hand and 51.6 kg. for the left as compared with 48.1 and 44.7 kg. for right and left, respectively, of Squad A. The individual subjects are here also very closely grouped about the general average.[2] Squad B in its low-diet averages for January 13, 19, and 27 has a total average for the right hand slightly above the normal (56.1 compared to 55.1 kg.) and for the left hand slightly below normal (50.9 compared

[1] In Squad A *Pea* and *Spe* were left-handed.

[2] *Kim*, *Lis*, *Sch*, and *Wil*, of Squad B, were left-handed; the first two are not included in the general averages.

TABLE 161.—*Squad A—Strength of grip at evening sessions.*
[Values in kilograms]

Date.	Hand.[1]		Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Ves.	Av.
1917.															
Oct. 27...	R.	M.	51.1	63.1	59.5	46.4	60.2	39.2	42.9	46.9	49.8	48.0	45.5	43.7	48.9
		S. D.	2.28	2.17	4.09	2.11	1.32	2.25	1.77	1.69	.91	2.87	2.49	2.36	1.94
		C.	4.5	3.4	6.9	4.5	2.2	5.7	4.1	3.6	1.8	6.0	5.5	5.4	4.1
	L.	M.	43.8	54.2	56.1	45.0	53.3	34.5	42.7	50.2	52.8	50.4	44.5	41.1	46.2
		S. D.	1.49	3.24	1.76	2.07	3.78	2.95	2.39	3.12	3.02	2.85	1.72	3.47	2.73
		C.	3.4	6.0	3.1	4.6	7.1	8.6	5.6	6.2	5.7	5.6	3.9	8.4	6.0
Nov. 10...	R.	M.	53.2	58.5	58.3	52.1	58.9	43.4	45.0	42.7	46.0	45.6	51.4	45.4	49.7
		S. D.	.98	.84	.68	1.74	.37	1.77	2.55	1.17	.89	1.83	1.50	1.53	1.33
		C.	1.8	1.4	1.2	3.3	6.3	4.1	5.7	2.7	1.9	4.0	2.9	3.4	3.4
	L.	M.	46.0	55.7	56.0	43.5	52.1	35.0	42.4	50.5	46.8	46.1	48.3	43.7	46.4
		S. D.	.71	1.99	1.14	1.42	1.32	2.03	2.85	2.80	1.17	3.15	1.47	1.91	1.77
		C.	1.5	3.6	2.0	3.3	2.5	5.8	6.7	5.5	2.5	6.8	3.0	4.4	3.9
Nov. 24...	R.	M.	49.0	53.3	56.3	50.7	58.6	42.4	48.0	39.0	44.1	47.3	51.9	45.9	48.3
		S. D.	2.55	1.40	.79	1.33	1.66	2.03	1.23	6.30	.56	2.32	2.39	1.24	1.97
		C.	5.2	2.6	1.4	2.6	2.8	4.8	2.6	16.2	1.3	4.9	2.7	2.7	4.4
	L.	M.	45.1	47.2	54.5	43.7	51.7	36.9	44.0	50.1	44.6	46.1	49.9	42.1	45.5
		S. D.	1.86	2.58	2.00	1.21	1.91	1.50	1.14	2.58	2.13	2.29	.97	1.74	1.76
		C.	4.1	5.5	3.7	2.8	3.7	4.1	2.6	5.2	4.8	5.0	1.9	4.1	3.9
Dec. 8...	R.	M.	49.9	50.0	51.3	48.0	56.5	46.1	41.3	39.7	44.4	45.5	52.9	46.4	47.5
		S. D.	1.47	.32	2.90	1.10	1.27	1.11	2.16	2.73	2.42	2.10	1.20	1.07	1.49
		C.	2.9	0.6	5.7	2.3	2.2	2.4	5.2	6.9	5.5	4.6	2.3	2.3	3.3
	L.	M.	46.4	44.1	53.3	40.3	48.4	36.1	42.2	50.8	42.7	43.4	46.2	40.9	43.8
		S. D.	1.24	1.96	1.99	.82	2.44	2.80	3.20	2.42	1.03	1.20	2.40	.66	1.90
		C.	2.7	4.4	3.7	2.0	5.0	7.8	7.6	4.8	2.4	2.8	5.2	1.6	4.4
Dec. 19...	R.	M.	51.2	51.1	53.8	51.6	54.6	41.2	44.0	43.0	43.3	.....	50.1	44.9	47.5
		S.D.	1.50	1.60	1.17	1.99	1.99	3.42	1.45	2.67	.52	.....	1.80	.58	1.75
		C.	2.9	3.1	2.2	3.9	3.6	8.3	3.3	6.2	1.2	.....	3.6	1.3	3.7
	L.	M.	43.6	39.2	53.2	43.8	44.9	34.3	40.4	49.0	42.8	.....	46.4	38.6	42.3
		S.D.	1.56	1.69	.68	1.66	2.35	.81	1.62	1.30	1.17	.....	2.18	1.06	1.54
		C.	3.6	4.3	1.3	3.8	5.2	2.4	4.0	2.7	2.7	.....	4.7	2.7	3.6
1918															
Jan. 12...	R.	M.	52.6	52.7	50.0	48.9	55.6	45.1	44.9	31.7	46.1	.....	48.7	44.8	47.1
		S.D.	1.36	.60	4.66	.66	1.86	1.39	1.28	5.81	1.11	.....	2.73	.59	1.74
		C.	2.6	1.1	9.3	1.3	3.3	3.1	2.9	18.3	2.4	.....	5.6	1.3	4.2
	L.	M.	44.7	45.5	54.0	43.1	48.5	39.5	40.7	54.4	49.1	.....	45.8	40.2	45.2
		S.D.	.60	2.53	3.36	1.16	1.90	1.34	.74	1.86	1.86	.....	2.25	.81	1.51
		C.	1.3	5.6	6.2	2.7	3.9	3.4	1.8	3.4	3.8	.....	4.9	2.0	3.3
Jan. 26...	R.	M.	52.7	52.1	55.7	51.2	52.4	44.3	45.0	44.0	43.1	.....	48.9	45.5	47.9
		S.D.	1.25	1.36	1.21	1.47	2.44	1.72	1.42	2.28	.76	.....	1.02	.45	1.42
		C.	2.4	2.6	2.2	2.9	4.7	3.9	3.2	5.2	1.8	.....	2.1	1.0	3.0
	L.	M.	46.8	46.6	55.2	43.9	46.7	36.8	40.7	48.3	44.2	.....	43.8	40.8	43.9
		S.D.	.25	1.96	.68	1.02	1.94	1.29	1.66	2.60	.87	.....	1.08	1.03	1.37
		C.	.5	4.2	1.2	2.3	4.2	3.5	4.1	5.4	2.0	.....	2.5	2.5	3.1
Feb. 2...	R.	M.	53.2	51.2	57.9	47.7	56.3	38.4	44.6	45.6	41.7	.....	49.9	46.2	47.5
		S.D.	.51	1.75	1.28	1.12	2.04	1.77	1.63	1.53	.98	.....	1.20	1.57	1.41
		C.	1.0	3.4	2.2	2.3	3.6	4.6	3.7	3.4	2.3	.....	2.4	3.4	3.0
	L.	M.	46.0	48.4	55.7	38.4	50.7	34.5	43.7	48.8	41.2	.....	47.4	41.6	44.1
		S.D.	.89	1.99	1.17	1.24	1.17	1.64	3.08	1.43	2.23	.....	1.50	2.62	1.78
		C.	2.0	4.1	2.1	3.2	2.3	4.8	7.1	2.9	5.4	.....	3.2	6.3	4.1
Low-diet av......	R.	M.	51.6	54.0	55.4	49.6	56.6	42.5	44.5	41.6	44.8	46.6	49.9	45.4	48.1
	L.	M.	45.3	47.6	54.8	42.7	49.5	36.0	42.1	50.3	45.5	46.5	46.5	41.1	44.7
May 21[2] ..	R.	M.	51.0	57.5	.....	.....	.....	.....	52.6	50.8	.....	47.5	.....	51.9	51.9
		S.D.	1.92	.71	.....	.....	.....	.....	1.54	4.06	.....	1.70	.....	.58	17.5
		C.	3.8	1.2	.....	.....	.....	.....	2.9	8.0	.....	3.6	.....	1.1	2.1
	L.	M.	45.8	53.9	.....	.....	.....	.....	52.4	55.7	.....	48.1	.....	46.1	50.3
		S.D.	1.72	1.16	.....	.....	.....	.....	3.64	1.64	.....	2.62	.....	2.22	21.7
		C.	3.8	2.2	.....	.....	.....	.....	6.9	2.9	.....	5.4	.....	4.8	2.6

[1]R. and L. are for right and left hands; M., mean or average; S. D., standard deviation; C., coefficient of variability. [2]Taken in Springfield.

TABLE 162.—*Squad B—Strength of grip at evening sessions.*
[Values in kilograms]

Date.	Hand.		Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917. Nov. 3	R.	M.	57.3	49.7	61.4	50.5	47.4	.....	54.0	60.0	.....	48.0	60.7	50.4	55.5	56.8	54.4
		S.D.	2.34	1.21	3.79	2.24	1.62	.....	3.24	.63	.....	1.30	2.71	1.19	2.66	2.01	2.27
		C.	4.1	2.4	6.2	4.4	3.6	.....	6.0	1.1	.....	2.7	4.5	2.4	4.8	3.5	4.2
	L.	M.	52.4	49.1	54.7	48.3	42.2	.....	48.2	54.7	.....	45.2	60.5	46.9	57.7	49.6	51.3
		S.D.	3.22	3.34	2.52	1.89	1.12	.....	3.15	1.78	.....	1.36	2.76	2.29	.51	1.93	2.30
		C.	6.1	6.8	4.6	3.9	2.7	.....	6.5	3.3	.....	3.0	4.6	4.9	0.9	3.9	4.5
Nov. 17	R.	M.	57.5	52.0	61.8	48.7	48.3	.....	58.1	58.0	.....	46.2	64.4	57.1	60.9	52.5	55.9
		S.D.	1.41	2.59	3.61	2.87	1.22	.....	2.31	2.10	.....	1.21	.58	1.02	.66	3.80	2.01
		C.	2.5	5.0	5.8	5.9	2.5	.....	4.0	3.6	.....	2.6	0.9	1.8	1.1	7.2	3.6
	L.	M.	56.8	51.5	53.6	45.1	38.9	.....	54.1	53.8	.....	45.5	63.2	51.2	57.0	49.0	52.7
		S.D.	1.03	2.02	2.22	2.18	1.07	.....	1.32	1.72	.....	1.48	1.69	1.47	.84	3.93	1.82
		C.	1.8	3.9	4.1	4.8	2.8	.....	2.4	3.2	.....	3.3	2.7	2.9	1.5	8.0	3.5
Dec. 15	R.	M.	.....	49.0	64.2	47.4	49.5	.....	60.6	58.2	.....	46.9	60.6	55.6	58.4	53.5	55.1
		S.D.	.....	2.28	1.29	3.57	1.27	.....	3.60	2.20	.....	.86	1.20	1.32	1.80	1.92	1.98
		C.	.....	4.7	2.0	4.7	2.6	.....	5.9	3.8	.....	1.8	2.0	2.4	3.1	3.6	3.6
	L.	M.	.....	50.8	59.2	44.9	40.7	.....	51.7	53.0	.....	47.0	59.2	48.7	43.5	51.8	50.6
		S.D.	.....	3.14	2.20	2.20	1.03	.....	1.91	2.28	.....	.71	2.80	1.89	1.95	3.44	2.25
		C.	.....	6.2	3.7	4.9	2.5	.....	3.7	4.3	.....	1.5	4.7	3.9	4.5	6.6	4.4
1918. Jan. 5	R.	M.	58.4	49.0	62.9	51.8	52.7	47.8	.....	.....	54.6	48.1	58.1	53.3	60.5	53.6	55.1
		S.D.	.97	3.11	2.46	2.87	1.60	1.44	.....	.....	1.32	1.28	.80	2.94	1.84	1.39	1.96
		C.	1.7	4.9	3.9	5.5	3.0	3.0	.....	.....	3.4	2.7	1.4	5.5	3.0	2.6	3.6
	L.	M.	54.5	52.1	55.6	47.7	40.3	48.8	.....	.....	54.9	48.1	54.3	47.5	58.2	48.6	51.8
		S.D.	1.38	2.11	1.36	.87	1.29	3.31	.....	.....	2.54	1.28	1.08	1.76	2.04	1.46	1.48
		C.	2.5	4.1	2.4	1.8	3.2	6.8	.....	.....	4.6	2.7	2.0	3.7	3.5	3.0	2.9
Normal av...	R.	M.	57.7	49.9	62.6	49.6	49.5	47.8	57.6	58.7	54.6	47.3	61.0	54.1	58.8	54.1	55.1
	L.	M.	54.6	50.9	55.8	46.5	40.5	48.8	51.3	53.8	54.9	46.5	59.3	48.6	54.1	49.8	51.6
Jan. 13	R.	M.	62.4	55.9	62.5	50.1	.....	46.4	56.3	.....	57.6	50.1	61.9	54.6	57.7	54.3	56.6
		S.D.	.80	.66	2.95	1.28	.....	2.31	2.38	.....	1.24	1.16	2.01	1.50	2.13	1.54	1.64
		C.	1.3	1.2	4.7	2.6	.....	5.0	4.2	.....	2.2	2.3	3.2	2.7	3.7	2.8	2.9
	L.	M.	58.2	56.2	41.5	45.9	.....	48.4	54.3	.....	54.3	48.2	56.0	47.8	56.1	51.2	51.5
		S.D.	0.81	1.94	3.59	2.78	.....	3.43	1.25	.....	1.47	.98	1.87	1.86	.92	1.21	1.72
		C.	1.4	3.5	8.7	6.1	.....	7.1	2.3	.....	2.7	2.0	3.3	3.9	1.6	2.4	3.3
Jan. 19	R.	M.	60.0	54.7	58.2	53.3	.....	45.4	57.5	.....	50.6	49.1	60.2	53.3	56.0	52.9	55.5
		S.D.	1.55	1.17	3.67	.98	.....	2.82	1.22	.....	2.33	.66	.93	1.60	.55	2.42	1.48
		C.	2.6	2.1	6.3	1.8	.....	6.2	2.1	.....	4.6	1.3	1.5	3.0	1.0	4.6	2.7
	L.	M.	55.6	60.0	40.5	48.2	.....	49.7	51.0	.....	49.3	46.6	56.4	47.6	51.9	50.8	50.9
		S.D.	3.37	1.92	3.35	1.89	.....	2.31	1.67	.....	1.12	.74	.86	2.35	1.80	2.23	2.02
		C.	6.1	3.2	8.3	3.9	.....	4.7	3.3	.....	2.3	1.6	1.5	4.9	3.5	2.4	4.0
Jan. 27	R.	M.	62.2	55.5	58.7	52.1	.....	47.0	56.7	.....	53.2	48.2	58.6	56.0	60.0	53.7	56.2
		S.D.	1.75	1.61	1.72	2.43	.....	1.23	2.84	.....	1.69	1.21	1.59	1.58	0.63	1.54	1.69
		C.	2.8	2.9	2.9	4.7	.....	2.6	5.0	.....	3.2	2.5	2.7	2.8	1.0	2.9	3.0
	L.	M.	57.9	55.9	37.9	45.4	.....	48.4	49.8	.....	53.4	45.7	55.4	50.2	54.2	50.6	50.3
		S.D.	1.43	2.01	3.64	1.32	.....	1.98	1.50	.....	1.36	1.17	1.59	1.21	2.87	2.50	1.92
		C.	2.5	3.6	9.6	2.9	.....	4.1	3.0	.....	2.5	2.6	2.9	2.4	5.3	4.9	3.8
Low-diet av...	R.	M.	61.5	55.4	59.8	51.8	.....	46.3	56.8	.....	53.8	49.1	60.2	54.6	57.9	53.6	56.1
	L.	M.	57.2	57.4	40.0	46.5	.....	48.8	51.7	.....	52.3	46.8	55.9	48.5	54.1	50.9	50.9

[1]R. and L. designate right and left hands; M., mean or average; S. D., standard deviation; and C., coefficient of variability.

to 51.6 kg.). The individuals indicate some change between the two groups of sessions. The most marked is in the case of *How*, whose low-diet average with the left hand of 40.0 differs widely from his normal average of 55.8 kg. He also shows a change in the same direction, but not so large, with the right hand, of 59.8 as compared with 62.6 kg. In their fluctuations the subjects are about equally divided, for example: with the right hand, 5 of them, *Fis, Har, Ham, Liv,* and *Tho,* show somewhat better results under the reduced diet condition, while the remaining subjects, and *How* in particular, show decreases.

The strength of grip data taken in the morning sessions are given in tables 163 and 164. This test was given in the same way as in the evening and with similar instructions. Averages are recorded for the 5 alternate trials with each hand. The standard deviation and coefficient of variability are also included for each average. It is unnecessary to comment upon the features of the individual data in these tables. In general they are consistent with those shown for the evening tests by the same subjects. The general average for the morning is definitely below that of the evening. In the case of Squad A the average for the right hand in the morning is 46.9 as compared to 48.1 kg. in the evening, and 43.3 as compared to 44.7 kg. in the evening with the left hand. With Squad B the normal average for the right hand in the morning is 52.9 and in the evening 55.1 kg. For the left hand it is 49.9 in the morning and 51.6 kg. in the evening. The low-diet averages also exhibit the same tendency: Right hand, morning, 52.7, evening, 56.1; left hand, morning, 47.5, evening, 50.9 kg. In general the morning results for strength of grip are 2 or 3 kilograms below those of the previous evening.

The data for the two squads may be most conveniently compared if plotted as curves. Figures 107 and 108 give the averages for the evening and morning tests, respectively. In figure 107 both curves for Squad A are definitely below those for B.[1] The right-hand curve is, in both cases, distinctly above that for the left hand. Squad A does slightly better in the second experiment than in the first, and from this point there is a gradual decline most prominent with the left hand. There is a rise with the left hand on January 12, the right remaining at the lower level but the left hand curve drops down again on January 26 and February 2. With B the right-hand curve shows a general but slight and intermittent improvement. The left hand curve has a reverse course, but the decline is also small, and not so conspicuous as in the case of Squad A. In the last three experiments (the low-diet period) there is no marked change.

[1] Williams (Arch. Intern. Med., 1917, **20**, p. 399), in his study of the Allen fasting treatment on the physical vigor of diabetics, measured the strength of grip with a Collins dynamometer. He found diabetics to be distinctly weaker than normal people. Muscular vigor in any subject was proportional to food tolerance rather than to the quantity ingested.

TABLE 163.—*Squad A—Strength of grip at morning sessions.*

[Values given in kilograms.]

Date.	Hand.[1]		Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av.
1917. Oct. 28...	R.	M.	46.7	53.5	60.6	48.9	59.8	33.5	47.6	46.1	46.2	47.5	47.1	46.8	47.6
		S.D.	2.44	1.51	1.32	2.15	.68	3.77	2.54	3.47	.97	2.97	3.50	1.86	2.29
		C.	5.2	2.8	2.2	4.4	1.1	11.2	5.3	7.5	2.1	6.3	7.4	4.0	5.1
	L.	M.	39.6	46.2	55.8	42.3	49.2	35.0	45.8	49.3	47.8	48.8	44.3	45.7	44.5
		S.D.	1.02	1.17	3.93	1.17	2.79	3.35	2.30	2.75	1.23	1.45	2.51	1.09	1.94
		C.	2.6	2.5	7.0	2.8	5.7	9.6	5.0	5.6	2.6	3.0	5.7	2.4	4.5
Nov. 11...	R.	M.	48.8	56.9	60.5	49.1	57.7	43.8	42.9	50.0	44.5	43.0	50.1	44.6	48.8
		S.D.	1.12	.80	.63	2.24	2.96	1.17	1.66	1.41	.63	1.92	1.20	3.17	1.64
		C.	2.3	1.4	1.0	4.6	5.1	2.7	3.9	2.8	1.4	4.5	2.4	7.1	3.4
	L.	M.	42.5	51.2	56.0	41.7	51.3	36.8	39.6	52.0	43.6	45.9	46.8	42.0	44.8
		S.D.	1.00	2.29	1.92	.75	2.69	1.03	1.50	1.27	.49	2.90	1.51	1.14	1.37
		C.	2.4	4.5	3.4	1.8	5.2	2.8	3.8	2.4	1.1	6.3	3.2	2.7	3.0
Nov. 25...	R.	M.	49.2	52.5	52.2	49.4	54.9	44.5	41.7	43.7	41.9	46.0	49.3	45.8	47.3
		S.D.	1.12	1.95	1.75	1.99	1.66	1.18	3.34	2.31	.80	1.70	1.21	2.80	1.84
		C.	2.3	3.7	3.4	4.0	3.0	2.7	8.0	5.3	1.9	3.7	2.5	6.1	4.0
	L.	M.	42.2	47.7	51.6	42.9	56.5	33.1	42.0	48.6	43.0	46.6	46.7	40.7	44.3
		S.D.	1.21	2.31	1.07	1.56	2.76	2.35	1.18	1.50	.32	2.22	1.08	2.01	1.63
		C.	2.9	4.8	2.1	3.6	4.9	7.1	2.8	3.1	0.7	4.8	2.3	4.9	3.7
Dec. 9...	R.	M.	49.9	51.6	49.3	47.3	50.6	44.1	39.6	38.9	40.9	44.8	44.8	45.1	45.3
		S.D.	1.07	1.88	1.83	1.54	2.65	1.11	2.18	4.70	.58	3.35	1.83	1.28	1.88
		C.	2.4	3.6	3.7	3.3	5.2	2.5	5.5	12.1	1.4	7.5	4.1	2.8	4.3
	L.	M.	41.8	45.2	50.8	40.9	45.5	33.8	39.0	46.9	41.2	46.5	42.1	38.1	41.5
		S.D.	.98	1.50	1.12	1.20	1.23	2.40	2.30	1.07	.68	1.38	.66	1.11	1.31
		C.	2.3	3.3	2.2	2.9	2.7	7.1	5.9	2.3	1.6	3.0	1.6	2.9	3.3
1918. Jan. 13...	R.	M.	50.9	52.0	54.3	49.0	54.4	44.7	43.3	38.9	43.5	.....	45.4	43.3	46.5
		S.D.	.80	1.23	.93	1.38	1.86	2.42	1.50	4.77	.95	.....	1.24	1.15	1.73
		C.	1.6	2.4	1.7	2.8	3.4	5.4	3.5	12.3	2.2	.....	2.7	2.7	4.1
	L.	M.	42.1	47.8	54.2	39.9	45.3	37.6	37.2	48.5	43.1	.....	41.0	40.3	42.3
		S.D.	1.24	1.63	.75	1.66	1.68	2.31	1.44	1.79	.66	.....	1.52	1.15	1.51
		C.	2.9	3.4	1.4	4.2	3.7	6.1	3.9	3.7	1.5	.....	3.7	2.9	3.6
Jan. 27...	R.	M.	49.2	50.2	55.6	45.9	52.9	45.2	41.3	41.6	40.2	.....	45.0	43.9	45.5
		S.D.	.75	3.08	1.90	1.02	2.08	1.36	2.04	2.98	1.03	.....	.89	.92	1.62
		C.	1.5	6.1	3.4	2.2	3.9	3.0	4.9	7.2	2.6	.....	2.0	2.1	3.6
	L.	M.	42.4	48.5	51.5	38.5	45.9	35.0	39.6	48.7	40.4	.....	41.1	39.9	42.0
		S.D.	1.20	1.60	1.95	1.24	3.01	1.52	1.20	2.09	1.88	.....	.80	1.56	1.61
		C.	2.8	3.3	3.8	3.2	6.6	4.3	3.0	4.3	4.7	.....	1.9	3.9	3.8
Feb. 3...	R.	M.	50.7	56.4	57.2	46.1	52.5	47.2	44.9	39.2	39.9	.....	50.1	42.8	47.0
		S.D.	.75	.86	.75	.92	1.14	1.47	.49	4.27	.58	.....	1.36	.25	1.21
		C.	1.5	1.5	1.3	2.0	2.2	3.1	1.1	10.9	1.5	.....	2.7	0.6	2.7
	L.	M.	43.6	52.5	54.3	38.5	46.0	39.3	45.0	46.2	40.9	.....	45.1	38.2	43.5
		S.D.	.58	.32	.93	2.44	1.14	1.60	1.55	.68	.86	.....	3.14	.40	1.27
		C.	1.3	6.1	1.7	6.3	2.5	4.1	3.4	1.5	2.1	.....	7.0	1.0	3.5
Low-diet av......	R.	M.	49.3	53.3	55.7	45.0	54.7	43.3	43.0	42.6	42.4	45.3	47.4	44.6	46.9
		S.D.	1.15	1.62	1.30	1.61	1.86	1.78	1.96	3.42	.79	2.49	1.60	1.66	1.74
		C.	2.4	3.1	2.4	3.3	4.2	4.4	4.6	8.3	1.9	5.5	3.4	3.6	3.9
	L.	M.	42.0	48.4	53.5	40.7	48.5	35.9	41.2	48.6	42.9	47.0	43.9	40.7	43.3
		S.D.	1.03	1.55	1.67	1.43	2.19	2.08	1.64	1.59	.87	1.99	1.60	1.21	1.52
		C.	2.5	3.6	3.1	3.5	4.5	5.9	3.9	3.3	2.0	4.3	3.6	2.4	3.6

[1]R. and L. designate right and left hands; M., mean or average; S. D., standard deviation; and C., coefficient of variability.

TABLE 164.—*Squad B—Strength of grip at morning sessions.*

[Values in kilograms.]

Date.	Hand.[1]		Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917 Nov. 4	R.	M.	56.3	51.5	61.1	50.6	44.4	.....	55.7	56.6	.....	46.5	59.4	51.9	58.0	52.5	54.4
		S.D.	1.78	2.23	1.32	1.39	3.15	.....	3.97	1.39	.....	1.14	2.54	2.15	1.82	1.41	1.98
		C.	3.2	4.3	2.2	2.7	7.1	.....	7.1	2.5	.....	2.5	4.3	4.1	3.1	2.7	3.6
	L.	M.	52.9	51.7	53.6	48.0	37.8	.....	47.8	49.2	.....	44.5	60.4	48.0	55.5	48.7	51.1
		S.D.	1.88	2.48	1.20	1.58	2.11	.....	3.72	1.21	.....	.95	1.39	1.64	1.00	1.47	1.73
		C.	3.6	4.8	2.2	3.3	5.6	.....	7.8	2.5	.....	2.1	2.3	3.4	1.8	3.0	3.4
Nov. 18	R.	M.	56.6	48.2	62.2	43.6	47.3	.....	55.6	54.8	.....	45.1	57.8	53.3	57.5	52.7	53.3
		S.D.	1.28	1.29	4.01	1.83	3.03	.....	2.01	1.57	.....	1.20	1.63	3.26	1.70	.93	1.91
		C.	2.3	2.7	6.4	4.2	6.4	.....	3.6	2.9	.....	2.7	2.8	6.1	3.0	1.8	3.6
	L.	M.	53.4	50.2	53.2	43.2	40.3	.....	47.7	50.2	.....	44.8	56.8	46.6	55.2	51.1	50.2
		S.D.	2.74	2.04	1.86	1.75	.40	.....	1.78	1.58	.....	.93	2.46	1.83	1.12	3.60	2.01
		C.	5.1	4.1	3.5	4.1	1.0	.....	3.7	3.1	.....	2.1	4.3	3.9	2.0	7.0	4.0
Dec. 16	R.	M.	.....	46.9	60.1	42.9	47.2	.....	55.6	55.0	.....	44.4	59.5	49.5	55.1	49.5	51.9
		S.D.	.....	1.39	3.38	3.38	2.45	.....	1.77	2.47	.....	1.77	1.10	1.34	.66	2.41	1.91
		C.	.....	3.0	5.6	7.9	5.2	.....	3.2	4.5	.....	4.0	1.8	2.7	1.2	4.9	3.7
	L.	M.	.....	47.3	50.1	44.6	36.3	.....	50.7	51.2	.....	44.8	58.7	45.1	52.2	45.9	48.8
		S.D.	.....	1.26	1.32	3.38	2.23	.....	5.08	2.77	.....	.98	1.36	1.27	1.03	1.96	1.96
		C.	.....	2.7	2.6	7.6	6.1	.....	10.0	5.4	.....	2.2	2.3	2.8	2.0	4.3	4.0
1918 Jan. 6	R.	M.	56.9	49.3	59.0	48.0	49.7	44.5	.....	.....	57.5	45.3	54.2	49.1	57.4	46.9	51.8
		S.D.	.99	1.33	5.24	1.82	.87	1.90	.....	.....	1.18	.93	1.91	2.58	1.36	1.83	2.00
		C.	1.7	2.7	8.9	3.8	1.8	4.3	.....	.....	2.1	2.0	3.5	5.3	2.4	3.9	3.9
	L.	M.	54.6	51.4	50.0	45.1	38.3	44.5	.....	.....	54.0	44.5	53.7	45.0	54.5	45.8	49.4
		S.D.	1.39	1.98	2.51	1.20	1.60	3.74	.....	.....	2.12	.63	2.25	1.05	.89	2.42	1.59
		C.	2.5	3.9	5.0	2.7	4.2	8.4	.....	.....	3.9	1.4	4.2	2.3	1.6	5.3	3.2
Normal av...	R.	M.	56.6	49.0	60.6	46.3	47.2	44.5	55.6	55.5	57.5	45.3	57.7	51.0	57.0	50.4	52.9
		M.	53.6	50.2	51.8	45.2	38.2	44.5	48.7	50.2	54.0	44.7	57.4	46.2	54.4	47.9	49.9
Jan. 14	R.	M.	60.0	51.0	54.0	45.7	.....	41.0	55.0	.....	54.1	46.6	57.7	52.1	54.7	48.8	52.6
		S.D.	2.10	.95	.57	1.66	.....	2.26	1.52	.....	.66	1.07	1.25	2.15	1.69	1.03	1.40
		C.	3.5	1.9	1.1	3.6	.....	5.5	2.8	.....	1.2	2.3	2.2	4.1	3.1	2.1	2.7
	L.	M.	54.0	54.1	34.3	40.8	.....	44.0	47.4	.....	52.7	42.6	52.6	46.0	51.8	46.2	47.0
		S.D.	1.52	1.77	1.89	3.11	.....	2.90	2.71	.....	.97	1.70	1.39	.84	1.63	2.80	1.94
		C.	2.8	3.3	5.5	7.6	.....	6.6	5.7	.....	1.8	4.0	2.6	1.8	3.1	6.1	4.1
Jan. 20	R.	M.	60.3	50.7	55.8	50.8	.....	45.1	50.4	.....	51.5	46.4	56.5	51.9	55.5	47.7	52.6
		S.D.	.40	2.66	1.44	2.29	.....	1.74	2.27	.....	1.10	1.02	1.89	2.11	1.18	2.54	1.78
		C.	6.6	5.2	2.6	4.5	.....	3.9	4.5	.....	2.1	2.2	3.3	4.1	2.1	5.3	3.4
	L.	M.	56.4	52.3	36.1	46.2	.....	46.1	43.3	.....	47.8	42.0	50.6	47.4	51.0	47.0	47.2
		S.D.	2.03	3.09	1.50	1.17	.....	3.18	2.48	.....	.51	1.10	2.42	.58	1.27	4.00	1.96
		C.	3.6	5.9	4.2	2.5	.....	6.9	5.7	.....	1.1	2.6	4.8	1.2	2.5	8.5	4.2
Jan. 28	R.	M.	59.0	52.1	59.2	50.8	.....	49.2	53.5	.....	53.4	46.6	55.7	50.7	55.2	47.3	53.0
		S.D.	.89	3.20	.93	2.62	.....	2.42	2.10	.....	1.50	.86	1.69	1.17	.93	.81	1.52
		C.	1.5	6.1	1.6	5.2	.....	4.9	3.9	.....	2.8	1.8	3.0	2.3	1.7	1.7	2.9
	L.	M.	56.5	50.8	42.5	45.3	.....	49.8	48.4	.....	51.2	42.1	53.7	44.1	52.4	48.2	48.4
		S.D.	2.59	1.12	1.97	2.48	.....	2.36	1.02	.....	.68	.73	1.50	1.39	.86	1.63	1.53
		C.	4.6	2.2	4.6	5.5	.....	4.7	2.1	.....	1.3	1.7	2.8	3.2	1.6	3.4	3.2
Low-diet av...	R.	M.	59.8	51.3	56.3	49.1	.....	45.1	53.0	.....	53.0	46.5	56.6	51.6	55.1	47.9	52.7
	L.	M.	55.6	52.4	37.6	44.1	.....	46.6	46.4	.....	50.6	42.2	52.3	45.8	51.7	47.1	47.5

[1]R. and L. designate right and left hands; M., mean or average; S. D., standard deviation; and C., coefficient of variability.

The difference in level between the curves of the two squads is significant but of unknown value, as records were not obtainable for the normal condition of Squad A before they began the reduced diet. As it was considered that the members of Squad A would have returned to somewhat near their normal condition by May 21, it was arranged that the 6 members of Squad A who still remained in college should take a strength of grip test with the same instrument and under the usual instructions and supervision. The data which were gathered are included in table 161 for the evening record. The data for each subject may be conveniently compared with the low-diet average immediately above. For May 21 *Bro* shows a right-hand average of 51.0 kg. as compared to a low-diet average of 51.6 kg., and a left-hand average of 45.8 compared to a low-diet average of 45.3 kg.; that is, with this subject there is practically no change. With the other 5 subjects, however, the condition is very different: *Can* shows for the right hand a rise from 54.0 to 57.5 and for the left hand from 47.6 to 53.9; *Moy's* record for the right hand changes from 44.5 to 52.6 and for the left hand from 42.1 to 52.4. *Pea* said his wrist was still weak and inefficient; his records show, however, an increase from 41.6 to 50.8 for the right hand and from 50.3 to 55.7 for the left hand. *Spe* gave a right-hand score which changed from 46.6 to 47.5, and for the left hand 46.5 to 48.1, and lastly, *Vea* shows right hand 45.4 to 51.9 and left hand a record of 41.1 as compared with his later average of 46.1. The averages for these 6 subjects of Squad A during the low-diet period were right hand, 47.3, left hand, 45.5, as compared with the scores for May 21 with right hand 51.9 and left hand 50.3. The variability figures for these records of May 21 are, on the average, the smallest found at any time for Squad A, thus indicating great consistency in the records of that date. It seems very

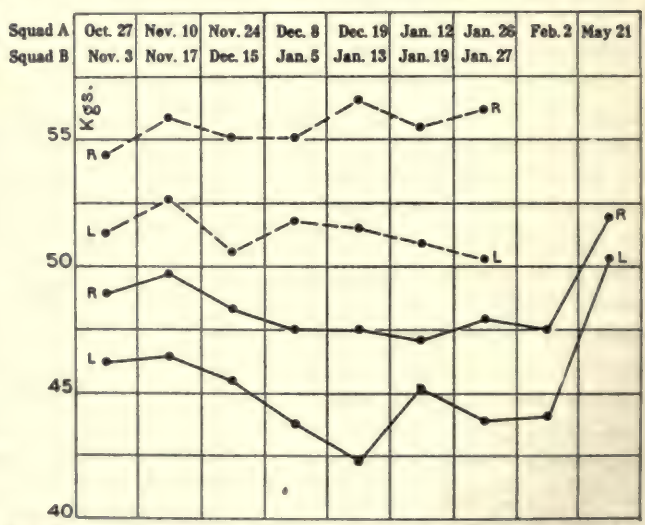

FIG. 107.—Averages for strength of grip at evening sessions and with six members of Squad A on one date following the low-diet experiment.

R and *L* designate right and left hands. Solid line curves represent Squad A, and broken lines Squad B.

evident that with the uncontrolled eating there was a change, at least with 5 out of 6 men, and the strength of grip had increased roughly 4.5 kg. with each hand. This is nearly enough to account for the difference in level of the two squads shown in figure 107. If a comparison is made between the low-diet averages for the 6 subjects under special consideration and the low-diet average for the whole group, as shown in table 161 (48.1 and 44.7 for the right and left hands, respectively), it will be noted that these 6 men average very nearly the same as the whole group. It is therefore permissible to plot points on figure 107, showing the level of the performance of May 21. This has been done at the right side of the figure. These two points are seen to be definitely above any other performance of Squad A and to be in the range of Squad B, although in the case of the right hand not so high.[1]

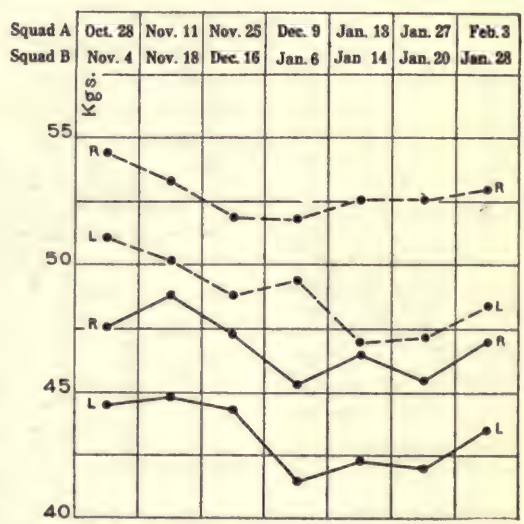

FIG. 108.—Averages for strength of grip at morning sessions.

R and *L* designate values for right and left hands. Solid line curves represent Squad A, and broken lines, Squad B.

The curves for the morning records (fig. 108) show the interesting result that both squads are a little nearer the same level, although Squad B is still at a higher level than Squad A. The gradual decline shown by the records of Squad B from the first performance of November 4 is striking. Squad B made their best morning record on the first morning experiment, November 4. It is difficult to assign a reason for this gradual decline in succeeding sessions. The conditions in the morning were somewhat different from those in the evening, since each subject was tested by himself in room B; consequently, when the subject was making his record he did not have the stimulating presence of someone sitting at the side watching. It is possible that this factor may be of considerable importance here, as it is frequently noted in the literature on strength of grip and ergographic experiments. Squad B with the left hand shows a marked drop on the three dates, January 14, 20, and 28, which were during the low diet. There was, during the same period, a very slight rise in the record with the right

[1] Of this group of 6 men tested on May 21, *Pea* and *Spe* were left-handed.

hand. Squad A made their be t record at the second morning session, November 11. Following this, the irregularity is not marked, and all of the averages are definitely lower. There was somewhat of a rise on the morning of February 3, probably assignable to the more or less stimulating conditions at the close of the experiment, as the strength of grip followed the walking and was the last test before the subject broke training.

The variability in the strength of grip is shown in figures 109 and 110 for the evening and morning performance, respectively. Separate curves are given for the right and left hands. There appear no conspicuous differences between the two squads in relation to this factor. The variability value is always small, never larger than 6 per cent, even though there is considerable relative fluctuation in its size. The curves cross and recross, but in general maintain the same level. In the case of the evening records (fig. 109), Squad A has relatively a large variabilitv with the left hand on October 27 (6 per cent). Following this, the variability usually ranges between 3 and 4 per cent. As the experiment continues, it tends to decrease. This irregular decrease in the variability is found with both squads and in both the evening and morning records, but is more prominent in the former. The small variability found on May 21 (see fig. 109) is remarkable and in striking contrast to that for October 27, the firs evening session, and for October 28, the first morning session (see fig. 110), even though 2½ months intervened between February 2 and May 21.

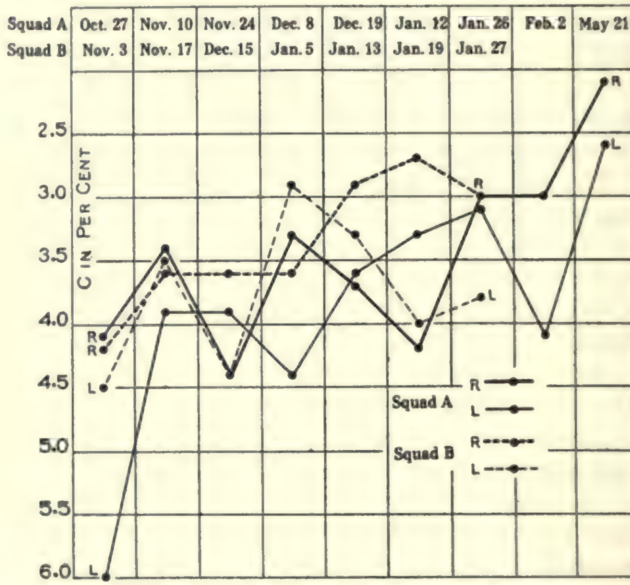

FIG. 109.—Variability in the average strength of grip at evening sessions.

R and *L* designate values for right and left hands.

In a strength test there are at least two conditions which favor increased variability: (1) any changing interest or fluctuating attention in connection with the test; (2) the extremeness of the muscular

efforts with the result of quick development of fatigue or conditions which produce pain. Squad A made better averages in their first two sessions than in any of the subsequent periods, and the variability tends to be largest; there would seem to be some connection between these two factors. The changes in variability with Squad B are not so marked; they were about the same level all the time, with some decrease in the case of evening work particularly.

In summarizing the effect of the reduced diet on the strength of grip, we have to consider these facts: (1) There are two squads of 10 men each with no apparent reason for believing that the average grip strength of one squad should be much greater than the other under normal conditions. With Squad A on reduced rations, we find a definite difference between the two groups of men. (2) Records taken with 6 of the members of Squad A after the reduced-diet period and at a time when it might be considered that the men had returned to approximately normal conditions, show, on the average, a strength of grip about 4.5 kg. greater than that demonstrated during the low-diet period. (3) There was a gradual reduction in the strength of grip with Squad A from the beginning until the last of the experiment. (4) In the 3 weeks' diet period with Squad B there was some reduction below the previous performance. (5) In all the records, the coefficient of variability for individual series of five trials remains quite constant at about 4 per cent, thus indicating uniformity of effort in the test. It would therefore seem that the strength of grip was definitely lowered by the reduced diet régime. In the absence of normal measurements for Squad A previous to the period of diet and for half of the men subsequent to the experiment, it is impossible to say how large the reduction may be. It is not unreasonable to believe that it averaged about 4 kg. in 50, which amounted to approximately an 8 per cent reduction in strength as exhibited in this test.

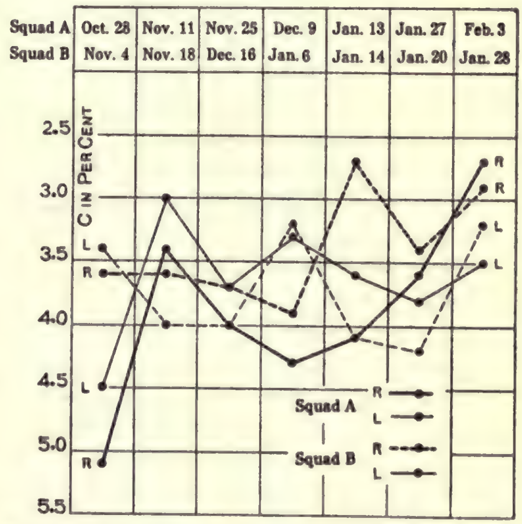

FIG. 110.—Variability in the average strength of grip at morning sessions.

R and *L* designate values for right and left hands.

(8) LATENCY, AMPLITUDE, AND REFRACTORY PERIOD OF PATELLAR REFLEX.[1]

Of all the human reflexes that may be elicited by appropriate stimuli, that of the patellar lends itself most conveniently to measurement. No doubt the method of recording the latency, amplitude, and refractory period of this reflex from the thickening of the quadriceps muscle is, all things considered, the most satisfactory technique.[2] The term "reflex arc" is associated with such ideas as simplicity and invariability, in short, constancy of response. Physiologists, however, who have worked with human reflexes, and specifically with the patellar reflex, have soon discovered that this is not a constant in its time relations or in its amplitude. Our data for the 63 young men of the normal series of 1917, with whom the patellar reflex was measured with identical apparatus and procedure as in the low-diet research, may be examined in connection with this matter of the variability of this reflex. In the first place, it is noteworthy that of the 63 men there were 15 from whom the reflex could not be obtained in measurable amplitude. Every effort was made to adjust the apparatus to exactly the proper height on the tendon, to see that the leg of the subject was in a comfortable position, and that the subject was relaxed, as indicated by the condition of his leg muscles. Our failure was, therefore, not because of lack of time or care in trying to secure the reflex. It was because under our conditions for stimulation and on that date the reflex could not be produced. In several of these cases, when trial was made with the legs crossed and by the usual clinical method, there was some reflex, but of course this was not measurable as to latency or amplitude under such conditions.

The 48 men from whom measurable series of reflexes were obtained gave an average latency (average of all individual averages) of 32 σ.[3] The standard deviation for this series of 48 patellar reflex latencies was 6.6 σ, the coefficient of variability, therefore, being 21 per cent. We may anticipate our results slightly here and point out that this coefficient of variability is larger than a similar coefficient for neuromuscular processes, such as reactions and muscle coordinations, which are usually considered much more complex than the patellar reflex. The average amplitude of the primary reflex for the 48 individuals was 15 mm. This is a magnification of 6 times the extent of actual muscle-thickening. With different subjects the average amplitude

[1]Measurement No. 7 (changes in pulse-rate occasioned by short periods of exertion) is discussed with the other pulse data; see p. 415.

[2]Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 36.

[3]This average is for the reflexes of the first stimulus. On page 155 it is explained that two pendulum hammers were used to stimulate for the reflex. The second hammer was to fall against the knee at a variable interval from the stimulus of the first. When this interval was short, there was no response, that is, the reflex was refractory. When it was fairly long there was a response, in some cases almost as large as the primary reflex. These secondary reflexes, however, which followed shortly upon the primary, are not counted in the averages. σ is used as an abbreviation for 0.001 second.

varied from 2 to 45 mm. The standard deviation for the series was 11.4 mm., thus showing a coefficient of variability for the series of 76 per cent.[1] The time interval separating the two stimuli to the patellar tendon was gradually changed to determine that time separation when the second stimulus failed to produce a measurable reflex. (See p. 157.) This interval (S) varied from 0.11 to 0.42 second. In 39 cases in which the measurements were fairly satisfactory, the average was 0.25 second.[2] The standard deviation for our series of 39 S values is 0.076. The coefficient of variability for this refractory period measure is found to be 30 per cent.[3]

We have mentioned the variability in the latency, amplitude, and the refractory period of the patellar reflex for different subjects. We might also call attention to a similar variability between successive series of records on the same subject. Dodge and Benedict have called attention to this factor and have given illustrative data on page 46 of their publication. It is known that in the case of the protective lid reflex, if we use sharp noises as stimuli for the eye wink, the individual gradually becomes accustomed to this stimulation and the wink is inhibited, either showing a large decrease in its amplitude or being absent altogether. The same series of changes occur in the case of the patellar reflex. The reason for it is not so obvious as in the protective lid reflex. Nevertheless the stimuli commonly become more or less ineffective in that the amplitude of the reflex decreases if the measurement is taken every few days. Something of the same phenomenon shows in most series of reflexes taken at one sitting. The first few of the set may be much larger than those which follow. This same condition is of course true also with lid reflexes.

In attempting to use the patellar reflex in this low-diet investigation we recognize these elements of difficulty in making the measurements uniform and in interpreting the data. However, in conformity with our general purpose of providing as many opportunities as possible for the unknown effect of a prolonged reduced diet to demonstrate itself in the neuro-muscular processes, and since it was not convenient to use other reflex measurements, we have employed it here. The results are rather disappointing in the sense that the data (see tables 165 and 166) appear to be so fragmentary. Of the members of Squad A the patellar reflex could never be secured from *Pea;* it was always

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[1]Dodge, Zeitschr. f. allg. Physiol., 1910, **12,** p. 27. It would appear that Professor Dodge's statement "I believe the amplitude of the response in the knee jerk should be used with extreme caution as an indicator of the variations of any one selected factor; slight variations in the mean should be viewed with especial distrust," is thoroughly justifiable.

[2]Dodge and Benedict and later Miles worked with a separation of 0.5 second. The secondary reflexes under these conditions were usually of considerably less amplitude than the primary reflexes, but the reflex arc was never totally refractory with this separation between the stimuli.

[3]It is rather unfortunate that in the form Dodge and Benedict (see Carnegie Inst. Wash. Pub. No. 232, 1915, p. 49, ff.) published their data the values for latency and for reflex amplitude were not given directly, but only the differences between successive series of such measurements; comparisons can not therefore be made.

very small or absent with *Pec* and *Bro*, and was exceedingly irregular with *Tom*. *Fre* served but a short time, and *Spe* was ill from December 19 to the end of the experiment. *Gar* showed a peculiar elastic vibration of the muscle which greatly complicated the curves and made many of them illegible and other readings untrustworthy. The averages in the extreme right-hand column of table 165 are from the 6 subjects, *Can*, *Kon*, *Gul*, *Mon*, *Moy*, and *Vea*, with whom reasonably complete records were obtained. Even with these there were a number of breaks. The one with *Kon* on October 13, was due to his coming into Squad A late, as explained on page 557. Opposite each date, and in the vertical column, the average values for latency, amplitude, and separation of stimuli are recorded for each subject. The average for the 6 men for September 29 shows 34 σ for latency, 22 mm. for

TABLE 165.—*Squad A—Patellar reflex latency, amplitude, and refractory period.**

Date.	Reflex.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.
1917															
Sept. 29	L.	50	37	32	38	35	30	30	([1])	55	40	32	37	34	34
	A.	3.7	23	31	10	9	30	25	....	4	19	19	14	33	22
	S.	12	20	([4])	13	15	([4])	19	....	30	26	28	14	24	17
Oct. 13	L.	50	43	....	44	34	35	44	([1])	([1])	46	45	54	35	42
	A.	5.0	22	....	8	10	30	8	....	....	12	12	4	24	15
	S.	12	21	....	50	26	27	23	....	....	40	29	([3])	([4])	24
Oct. 27	L.	40	42	36	32	35	35	43	([1])	([1])	33	38	36	....	38
	A.	11	11	17	8	13	19	3	....	....	11	3	13	....	13
	S.	21	19	28	26	24	37	22	....	....	44	([2])	([3])	....	26
Nov. 10	L.	44	45	37	42	34	36	41	([1])	([1])	34	([1])	32	....	38
	A.	4	15	14	3	23	19	3	....	....	18	....	18	....	15
	S.	18	20	26	37	27	([4])	39	....	....	42	....	[7]11	....	25
Nov. 24	L.	([1])	44	35	39	32	33	39	([1])	([1])	35	([1])	34	....	36
	A.	....	15	22	7	19	25	5	....	....	12	....	14	....	17
	S.	....	26	([3])	24	21	([4])	([4])	....	....	37	....	([3])	....	24
Dec. 8	L.	([1])	40	36	40	33	29	38	([1])	([1])	38	([1])	30	....	34
	A.	....	26	20	6.2	15	26	8.8	....	....	7	....	24	....	20
	S.	....	31	25	([3])	([3])	38	36	....	....	([6])	....	([3])	....	32
Dec. 19	L.	42	36	39	([5])	32	35	37	([1])	([1])	....	([1])	30	....	35
	A.	2.6	19	12	....	21	18	12	....	....	....	....	19	....	17
	S.	([4])	14	20	([3])	19	29	25	....	....	....	....	[3]29	....	23
1918															
Jan. 12	L.	47	42	31	38	37	37	40	([1])	([1])	....	32	36	....	37
	A.	4.5	21	28	3	6.8	17	6.3	....	....	....	27	16	....	16
	S.	([2])	37	19	([3])	[3]12	37	([2])	....	....	....	34	([3])	....	26
Jan. 26	L.	([1])	41	35	([5])	34	31	44	([1])	([1])	....	36	46	....	39
	A.	....	23	14	....	12	30	6.6	....	....	....	10	7.4	....	16
	S.	....	23	20	([3])	20	30	26	....	....	....	24	([3])	....	25
Feb. 2	L.	44	35	38	39	34	31	34	([1])	([1])	....	([1])	41	....	36
	A.	2.2	31	12	3.5	11	32	13	....	....	....	....	9.2	....	18
	S.	([2])	22	17	([3])	[3]26	35	26	....	....	....	....	([3])	....	25

*L., A., and S. designate latency in 0.001 ″(σ), amplitude, in mm., and separation in 0.01″. In the body of the table the index figures refer to the following notes:

[1]No reflexes.

[2]No failures with short S.; all very small.

[3]Summation evident.

[4]Second contact out of order.

[5]Illegible.

[6]Irregular voluntary contraction following primary reflex.

[7]Leg feels tighter against apparatus.

amplitude, and 0.17 second for separation, *i. e.*, refractory period. These values are in the same range as those mentioned for the series of 1917, which were 32 σ, 15 mm., and 0.25 second. The individual subjects do not show extraordinary variation among themselves or with any individual from date to date.

In the case of Squad B there were only 4 men, *Fis*, *Har*, *Sne*, and *Tho*, with whom the patellar reflex was usually present in measurable amplitude and whose records are reasonably complete for the series of experiments. On the first date, October 6, these four show averages of 37 σ for latency, 23 mm. for amplitude, and 0.18 second for refractory period separation. All of the values, considering the process under discussion, are in reasonable agreement with the previous values which have been mentioned as possible standards.

TABLE 166.—*Squad B—Patellar reflex latency, amplitude, and refractory period.**

Date.	Reflex.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917.																
Oct. 6...	L.	39	36	40	42	....	....	39	36	....	34	37	35	51	44	37
	A.	15	19	14	5	....	....	4	32	....	5	19	39	3	5	23
	S.	18	(4)	19	(4)	....	....	(1)	20	....	(2)	13	24	24	(4)	18
Nov. 3...	L.	41	39	53	38	44	....	(1)	26	....	44	37	32	40	38	37
	A.	6.8	11	1	4	6	....	....	30	....	2	23	39	18	3	20
	S.	18	18	(2)	24	(2)	....	....	28	....	(2)	15	23	[3]17	19	18
Nov. 17...	L.	51	37	50	(1)	45	....	(1)	33	....	(1)	39	48	45	(1)	44
	A.	4	18	5	....	5	....	....	18	....	....	21	5	3	....	12
	S.	19	24	(1)	....	49	....	....	35	....	....	19	25	20	....	22
Dec. 15...	L.	....	38	(1)	39	(1)	....	(1)	34	....	(1)	36	34	(1)	(1)	36
	A.	....	7.9	....	3.5	....	....	....	30	....	....	22	21	....	....	17
	S.	....	15	....	(2)	....	....	....	26	....	....	15	25	....	....	18
1918.																
Jan. 5...	L.	34	32	43	(1)	(1)	39	....	....	(1)	(1)	37	36	39	38	35
	A.	20	18	3	....	....	12	....	....	....	....	20	36	5	4.5	23
	S.	20	13	(2)	....	....	19	....	....	....	....	16	25	12	13	18
Jan. 13...	L.	37	39	44	(1)	....	(1)	(1)	....	(1)	(1)	36	38	39	(1)	37
	A.	10	7.3	7.4	....	....	....	....	....	....	....	25	26	3	....	17
	S.	15	[3]21	12	....	....	....	....	....	....	....	18	25	33	....	20
Jan. 19...	L.	36	42	(1)	(1)	....	(1)	(1)	....	(1)	(1)	38	39	(1)	(1)	39
	A.	4.6	3.6	....	....	....	....	....	....	....	....	23	12	....	....	11
	S.	(2)	(2)	....	....	....	....	....	....	....	....	13	18	....	....	15
Jan. 27...	L.	42	38	46	(1)	....	(1)	(1)	....	(1)	(1)	38	40	(1)	(1)	39
	A.	5.8	4.2	3.8	....	....	....	....	....	....	....	20	12	....	....	10
	S.	37	(3)	(2)	....	....	....	....	....	....	....	[3]13	24	....	....	25

*L., A., and S. designate latency in 0.001 second (σ), amplitude in millimeters, and separation in 0.01 second. In the body of the table the index figures refer to the following notes:
[1]No reflexes.
[2]No failures with short S.; all very small.
[3]Summation evident.
[4]Second contact out of order.

It will be more convenient to compare the results with the two squads under conditions of normal eating and reduced diet from the plotted values in figure 111. The solid lines are for Squad A, the broken lines for Squad B. The two curves at the top of the figure give the latency. Beginning with 34 σ on September 29, Squad A in their second experi-

ment showed a reflex time lengthened to 42 σ. The latency was also longer than normal in the next three experiments, October 27, November 10, and November 24. On December 8 it was the same value as the normal, but on the succeeding four dates it was longer, conspicuously so on January 26. Squad B began with a longer latency than A. The first two experiments separated by 1 month show the same latency, 37 σ. At the next date this was lengthened to 44 σ, a rather conspicuous and unaccountable change.[1] On De-

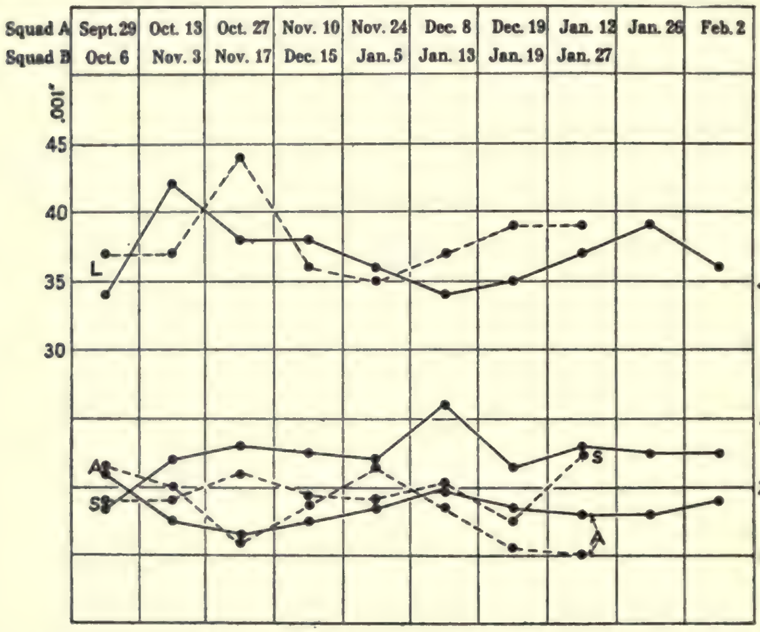

FIG. 111.—Patellar reflex averages.

L, latency; *A*, amplitude, and *S*, refractory period separation. The scale at the left is for 0.001 second, that at the right is for millimeters in the case of *A* and for 0.01 second for *S*. Solid lines represent Squad A, and broken lines Squad B.

cember 15 and January 5 the latency was slightly shorter than on the previous days, October 6 and November 3. On January 13 it was at the initial level, that is, 37 σ. This was the first low-diet date. On the next two, January 19 and 27, the latency was longer than at any other point save November 17.

The curves for the amplitude of the reflexes tend in each case to be the complement of those for the latency. When the latency is long the amplitude is small, and *vice versa*. Squad A shows a decrease in the amplitude for October 13, 27, and November 10. This accompanied the increase in latency. Squad B likewise shows a decrease in amplitude on November 17 with their associated latency of 44 σ, but

[1]See discussion of November 18 in relation to speed of eye movements, page 621.

the amplitude was still smaller on the last two low-diet dates, January 19 and 27. The refractory period (*S*) increases after the one normal date, September 29, with Squad A. It is unusually long on December 8. Otherwise it is fairly uniform throughout the low diet sessions, and is usually about 0.25 second. In the case of the four men of Squad B with whom data could be secured there seems no significant change until the very last date, January 27. This was on low diet, but it must be noted to the contrary that the previous date, January 19, which was also during the low-diet period, shows the shortest refractory interval found with these men, but this average was for only two subjects, *Sne* and *Tho*.

The footnotes in tables 165 and 166 indicate a large number of cases in which the tendency to summation of stimuli was present, *i. e.*, the production of one reflex for the two blows. This phenomenon of summation was found in only two cases with the normal series of 1917; it was not found with any of the 26 men of Squads A and B in the first measurement of the patellar reflex, and appeared only once (with *Van*, November 3, table 166) during normal dietetic conditions. With the reduced diet it was rather frequent (see *Har*, January 13 and 27, *Sne*, January 27, for Squad B, and many other illustrations with Squad A). When the summation of the two stimuli produced but one reflex it is of course impossible to give a figure for the refractory period. That stimuli of 100-gram hammers falling through 90°, which are normally rather intense stimuli for the patellar reflex, should become to the reflex as subliminal stimuli and only be effective when two of them succeed each other by a short interval demonstrates the fact that conditions exist in which the reflex irritability has become definitely less than normal. Whether this is primarily due to the reduced diet can not be absolutely proved from these data. The change may be in part from adaptation to the form of stimuli.

The evidence for the effect of the reduced diet upon the patellar reflex as a neuro-muscular measurement is not uncomplicated. It is our opinion, however, that there was a tendency for the reflex to be less irritable when the subjects were on the reduced diet.

(9) REACTION TIME FOR TURNING THE EYE TO A NEW POINT OF REGARD.

The time required for the eye to change the direction of the line of regard to an object appearing suddenly somewhere in the field of vision usually ranges from 150 to 250 σ, depending somewhat upon the amount of practice that the subject has had in the test. This measurement was used in the normal series of 1917; the apparatus and procedure were identical with that employed in the low-diet research. From 10 to 35 reactions were obtained on each subject. A larger number than 10 was taken on every subject, but occasionally, for one cause or another, some of the records would not be legible. Records from the

63 men in the series of 1917 show a general average of 244 σ, with a standard deviation of 46 σ; the individual averages range from 176 to 415 σ. Besides the individual with the average of 415 σ, which may not be a typical eye reaction, there were 3 other men in the normal series of 1917 who had reaction times of 340 σ or longer, that is: 342, 347, and 346 σ. Not one of the 63 subjects had previously served in this measurement. It was deemed of interest to take account of the shortest reactions which the individual subjects made,[1] as these minimum reaction times would appear to be less complicated by fluctuations in attention than is the general average of a series of reactions. The five shortest reactions made by each of the 63 men were therefore averaged. The general average of the 63 minimum averages shows 193 σ, with a standard deviation of 44 σ.

With but few exceptions, all of the eye reactions for the men of the normal series of 1917 were included in the averages. An inspection of the records of prolonged series of reactions taken with other individuals and also in the present low-diet research reveals the fact that frequently the first reaction made by a subject is unusually long and apparently quite out of uniformity with the subsequent reactions. On the other hand, these long initial reactions were not invariably found. While on general grounds it is not permissible to omit certain data on the supposition that it fails to fit in with one's standard of normality, yet it is possible to adopt some arbitrary method of dealing with such difficulties. The following rules were employed in averaging the eye-reaction data for this research:

(1) If, in the first set of eye reactions taken with a subject, that is, the first time this measurement was made on him, the first two reactions were abnormally long (350 σ or longer), they were *both* omitted from the average and considered as preliminary practice.

(2) Two plates were taken on the subject at each sitting or experimental evening. At each subsequent evening after the first, if the first reaction on either plate was abnormally long, it was also omitted from the average and considered as preliminary practice for the evening.

(3) Abnormally long reactions which occurred at any other places in the records than those specified were invariably included in the averages.

The individual eye-reaction time averages with standard deviations and coefficients of variability are given in tables 167 and 168 for Squads A and B, respectively. Squad A shows 231 and Squad B 237 σ as averages for the first reactions taken from the two groups of men with this technique. The average standard deviation in each case amounts to 20 per cent of the reaction time, the two standard deviations being

[1]Diefendorf and Dodge, Brain, 1908, 31, p. 472.

47.9 and 50.6 σ respectively. These values correspond very nearly with the 244 σ, and coefficient of variability of 19 per cent for the normal series of 1917. The averages for Squads A and B are about 10 σ less, due, no doubt, to our method of dealing with the preliminary long reactions just mentioned. The average reaction times for Squads A and B for other dates than October 28 and November 4, with the exception of the fragmentary data for November 11 (Squad A), always show smaller values than on the original first date. Such a practice effect is normal for untrained subjects in this measurement. It was found by Dodge and Benedict in the eye reaction data in their alcohol investigation.[1] It is clearly evident in an unpublished series of eye reactions secured with trained subjects in this Laboratory; it also shows definitely in this low-diet research.

TABLE 167.—*Squad A—The eye-reaction time and its variability.*
[M. in σ, S. D. in σ, and C. in per cent.]

Date.	Reaction.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av.
1917 Oct. 28.	M.	331	181	244	253	185	255	225	237	223	277	195	225	231
	S.D.	61	26	82	72	28	57	65	52	47	68	32	39	47.9
	C.	18.4	14.4	33.6	28.4	15.1	22.3	28.9	21.9	21.1	24.5	16.4	17.3	20.4
Nov. 11.	M.	(2)	[1]235	234	[1]240	(2)	(2)	241	261	(2)	262	(2)	192	233
	S.D.	.....	62	41	26	.....	.....	59	69	.....	49	.....	20	47.2
	C.	.....	26.4	17.5	10.8	.....	.....	24.5	26.4	.....	18.7	.....	10.9	19.8
Nov. 25.	M.	223	175	223	234	311	240	205	215	240	247	227	209	218
	S.D.	65	26	77	65	52	59	37	41	83	50	84	44	55.6
	C.	29.1	14.9	34.5	27.8	24.6	24.6	18.0	19.0	34.6	20.2	37.0	21.0	25.1
Dec. 9.	M.	207	170	234	217	170	200	211	219	200	276	210	189	199
	S.D.	65	30	94	59	26	32	40	48	33	75	66	25	42.4
	C.	31.4	17.6	40.2	37.2	15.3	16.0	19.0	21.9	16.5	27.2	31.4	13.2	22.0
1918 Jan. 13.	M.	243	178	211	210	184	226	213	227	226	.....	201	188	210
	S.D.	56	32	70	41	25	36	33	49	46	.....	36	22	37.6
	C.	23.0	18.0	33.2	19.5	13.6	15.9	15.5	21.6	20.3	.....	17.9	11.7	17.7
Jan. 27.	M.	242	(2)	156	203	180	199	209	259	206	.....	196	180	208
	S.D.	53	.....	22	33	39	25	33	84	32	.....	28	17	38.2
	C.	21.9	.....	14.1	16.3	21.7	12.6	15.8	32.4	15.5	.....	14.3	9.5	17.8
Low-diet av....	M.	249	188	217	226	186	224	217	236	219	266	206	197	217
	S.D.	60	35	64	49	34	42	45	57	48	61	49	28	44.8
	C.	24.8	18.3	28.9	23.3	18.1	18.3	20.3	23.9	21.6	22.7	23.4	13.9	20.5

[1]Very few data secured, but all are averaged in. [2]Action of shutter defective.

For the individual men of Squad A, the average reaction times for the whole series, from October 28 to January 27, range from 186 σ (*Gul*) to 249 σ (*Bro*). *Spe* shows an average, 266 σ, which is still higher. He did not, however, have so much opportunity for practice. All his reaction records show abnormally long times. The average variability for the individual subjects ranges from 18 to 29 per cent. The average reaction time for the whole experiment for the ten men

[1]Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 89.

is 217 σ, with an average individual variability of 20.5 per cent. With Squad B the general average for the 3 normal experiments is 224 σ, with like variability of 20.5 per cent. The average for the 2 low-diet experiments is 206 σ, with a variability of 19 per cent. The averages and variabilities for the individual subjects are not particularly noteworthy.

There were no normal eye-reaction experiments for Squad A. The total number of these measurements was further reduced by the tread-mill experiments on January 6 and 28 with Squad B, and on February 3 with Squad A, and the standard electrocardiograms on December 20 with Squad A, as on all four dates the morning psychological program had to be omitted.[1]

TABLE 168.—*Squad B—The eye-reaction time and its variability.*
[M. in σ, S. D. in σ, and C. in per cent.]

Date.	Reaction.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917																
Nov. 4..	M.	207	269	298	221	239	.....	268	252	.....	248	223	225	202	204	237
	S.D.	44	48	62	39	48	.....	91	50	.....	60	45	28	52	37	50.6
	C.	21.3	17.8	20.8	17.6	20.1	.....	33.9	19.8	.....	24.2	20.2	12.4	25.7	18.1	21.2
Nov. 18..	M.	207	.....	285	175	202	.....	230	200	.....	246	212	202	209	179	216
	S.D.	30	.....	59	33	42	.....	44	35	.....	45	40	22	54	36	40.3
	C.	14.5	.....	20.7	18.9	20.8	.....	19.1	17.5	.....	18.3	18.9	10.9	25.8	20.1	18.6
Dec. 16..	M.	.....	252	234	217	197	.....	268	175	.....	237	191	195	203	190	220
	S.D.	.....	54	53	48	45	.....	91	40	.....	45	32	28	40	48	48.7
	C.	.....	21.4	22.6	22.1	22.8	.....	34.0	22.9	.....	19.0	16.7	14.4	19.7	25.3	21.7
Normal av..	M.	207	261	272	204	213	.....	255	209	.....	244	209	207	205	191	224
	S.D.	37	51	58	40	45	.....	75	42	.....	50	39	26	49	40	46.5
	C.	17.9	19.6	21.4	19.5	21.2	.....	29.0	20.1	.....	20.5	18.6	12.6	23.7	21.2	20.5
1918																
Jan. 14..	M.	199	236	226	206	.....	240	238	.....	207	223	202	185	210	183	211
	S.D.	37	56	37	47	.....	69	52	.....	42	44	42	28	48	33	42.4
	C.	18.6	23.7	16.4	22.8	.....	28.7	21.8	.....	20.3	19.7	20.8	15.1	22.9	18.0	20.0
Jan. 20..	M.	204	218	200	195	.....	221	243	.....	194	219	180	169	194	175	200
	S.D.	36	37	28	22	.....	70	90	.....	26	45	41	20	28	22	36.9
	C.	17.6	17.0	14.0	11.3	.....	31.7	37.0	.....	13.4	20.5	22.8	11.8	14.4	12.6	17.9
Low-diet av......	M.	202	227	213	201	.....	231	241	.....	201	221	191	177	202	179	206
	S.D.	37	47	33	35	.....	70	71	.....	34	45	42	24	38	28	39.7
	C.	18.1	20.4	15.2	17.1	.....	30.2	29.4	.....	16.9	20.1	21.8	13.5	18.7	15.3	19.0

The available data for Squads A and B are plotted in figure 112. The two upper curves are for the variability and they show about 20 per cent for both squads in the first two experiments. In the third experiment with each squad there was a definite increase which, with Squad A, was to about 25 per cent. As seen in table 167, several men in Squad A showed unusually high variabilities in that experiment, as, for example: 34.5, 34.6, and 37 for *Kon*, *Pec*, and *Tom*. These values are high enough to account for this fluctuation. With Squad B the percentage for the third experiment was 21.7. This is not a large

[1]The fragmentary data for Squad A on November 11 are due to a technical difficulty in the apparatus; the subjects were in no way to blame.

enough fluctuation to be particularly noteworthy. Near the end of the experiment the eye reaction time decreased, and the variability was also smaller. The curves for the general averages are at the bottom of the figure. Squad B shows a rather consistent practice effect from the beginning to end, with the exception of a slight decrease in the third experiment, which corresponds with what has been noted above for the variability. There was no lengthening of reaction time associated with the period of food reduction for this squad. Squad A shows no significant change in the second experiment over their first one. The data for the second experiment are very fragmentary; indeed, they might have been omitted, since on account of the faulty action of the shutter (see *S* in figure 30), many of the shorter reactions failed to appear on the records. There was improvement up to December 9 and slightly lengthened reactions during January. The increase following the shortest reaction-time average of December 9 was approximately 5 per cent.

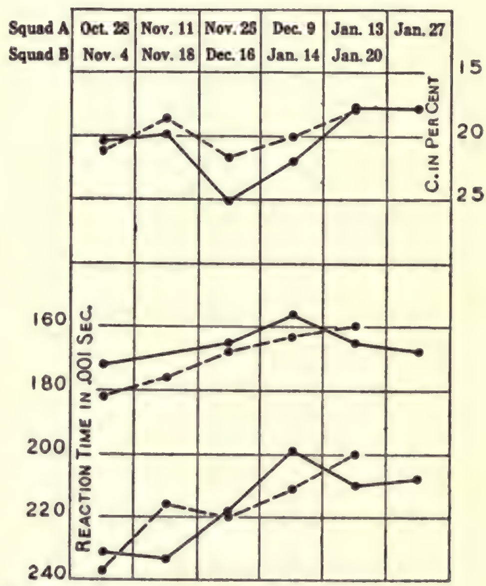

FIG. 112.—Eye-reaction time and its variability.

Solid lines represent Squad A and broken lines Squad B. The two curves at the bottom represent average reaction time; the two in the middle are for the five shortest reactions made by each subject at each experiment; the two curves at the top show the coefficients of variability.

For comparison with the general averages, we may give attention to the short reactions made by the various subjects. Short reactions, which are at the same time true reactions, would seem theoretically to measure the real process involved better than the average of all reactions, many of which are unavoidably complicated by fluctuations in attention and other disturbing conditions, objective as well as subjective. The 5 shortest reactions made by each subject at each experiment were averaged (see tables 169 and 170) and the averages of these figures for the 10 men of Squads A and B used to plot the curves shown in the middle of figure 112. The initial values are 172 σ and 182 σ for Squads A and B, respectively. The similar value for the normal series of 1917 previously referred to was 193 σ. The curve for Squad B shows a gradual and uninterrupted practice effect from the value 182 σ to the final value of 160 σ. Squad A shows a practice effect approximately equal or parallel to that of Squad B, up

to and including December 9. In the last 2 experiments there was a definite, accumulative decline. This agrees very well with the findings for the general averages of the same squad on the same dates. It therefore appears that the eye-reaction time according to the technique here employed was not changed in any significant way by the reduced diet. According to the present standards our averages and the variability values with the fluctuations in these are well within normal limits.

TABLE 169.—*Squad A—Average of shortest eye reactions.*
[Values in σ.]

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av.
1917.													
Oct. 28....	244	146	179	145	138	188	173	178	181	190	155	183	172
Nov. 11....	.....	.....	.....	.....	.....	.....	180	193	.....	209	.....	170	.....
Nov. 25....	176	139	164	157	168	180	171	167	171	173	158	167	165
Dec. 9....	158	134	156	152	141	155	170	178	160	184	157	158	156
1918.													
Jan. 13....	177	142	144	164	146	181	169	186	176	.....	156	156	165
Jan. 27....	180	.....	135	169	156	162	174	183	167	.....	162	159	168

TABLE 170.—*Squad B—Average of shortest eye reactions.*
[Values in σ.]

Date.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917.															
Nov. 4........	163	208	215	168	178	....	197	191	....	194	170	192	154	163	182
Nov. 18........	167	....	212	157	141	....	180	156	....	194	178	181	163	150	176
Dec. 16........	....	197	192	154	151	....	173	....	....	187	155	158	163	137	168
1918.															
Jan. 14........	155	171	185	153	161	....	180	....	160	172	150	156	156	150	163
Jan. 20........	165	174	176	161	162	....	170	....	160	166	137	145	159	142	160

(10) REACTION TIME FOR SPEAKING 4-LETTER WORDS.

When a list of 25 familiar 4-letter words is presented in chance order, the reaction time for responding to such stimuli is approximately twice that of the eye-reaction time.[1] In tables 171 and 172 for Squads A and B, respectively, the average reaction time, with the standard deviation and the coefficient of variability, is recorded for each subject and for each session. The word reactions were first taken at the second experimental session with each squad, hence there are no normal values for Squad A. There are 4 normal dates for Squad

[1]As was shown by Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 100, there is an instrumental latency with this exposure apparatus amounting to 37 σ. The values which have been entered in the tables are simply for comparative purposes, and this factor has *not* been subtracted from them. The same is true of the published eye reaction data, where the instrumental latency is 20 σ. (See footnote, p. 163.)

B. Word reactions were taken on 9 evenings with Squad A. The averages for these individual subjects are at the bottom of table 171 and range from 415 σ for *Bro* to 597 σ for *Can*, with a total average for the 10 men of 486 σ. The coefficient of variability for the individual series of reactions is from 7 to 13 per cent of the reaction time, the average for the 10 subjects being 9.3 per cent. These average figures for Squad A compare fairly well with the results found with normal

TABLE 171.—*Squad A—Time and variability of word reaction.*
[M. in σ; S. D. in σ; and C. in per cent.]

Date.	Reaction.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.
1917. Oct. 13..	M.	444	679	.....	490	457	513	473	574	468	488	454	476	441	503
	S.D.	34	82	.....	49	63	64	77	62	54	46	45	58	51	58.8
	C.	7.8	12.1	.....	10.0	13.8	13.8	16.3	10.8	11.5	9.4	9.9	12.2	11.6	11.8
Oct. 27..	M.	413	658	550	472	439	512	458	527	440	554	465	470	.....	485
	S.D.	45	69	125	35	38	40	43	53	53	84	57	38	.....	47.1
	C.	10.9	10.5	22.7	7.4	8.7	7.8	9.4	10.1	12.0	15.2	12.3	8.1	.....	9.7
Nov. 10..	M.	436	566	506	478	443	491	439	507	452	485	530	475	.....	482
	S.D.	45	40	43	27	28	47	31	54	67	32	87	50	.....	47.6
	C.	10.3	7.1	8.5	5.7	6.3	9.6	7.1	10.6	14.8	6.6	16.4	10.5	.....	9.8
Nov. 24..	M.	414	576	514	455	443	499	518	514	483	508	438	468	.....	481
	S.D.	28	36	46	56	29	33	64	52	68	40	40	23	.....	42.9
	C.	6.8	6.3	9.0	12.3	6.6	6.6	12.3	10.1	14.1	7.9	9.1	4.9	.....	8.9
Dec. 8..	M.	403	578	505	477	429	499	478	522	460	492	438	448	.....	473
	S.D.	30	37	62	43	34	48	54	41	72	37	31	31	.....	42.1
	C.	7.5	6.4	12.3	9.0	7.9	9.6	11.3	7.9	15.7	7.5	7.1	6.9	.....	8.9
Dec. 19..	M.	399	583	506	464	435	504	482	515	466	.....	457	456	.....	476
	S.D.	26	29	49	40	21	36	49	41	64	.....	57	26	.....	38.9
	C.	6.5	5.0	9.7	8.6	4.8	7.1	10.2	8.0	13.7	.....	12.5	5.7	.....	8.2
1918. Jan. 12..	M.	397	568	501	477	463	565	556	549	507	.....	453	468	.....	500
	S.D.	28	36	45	44	20	47	50	60	61	.....	34	49	.....	42.9
	C.	7.1	6.3	9.0	9.2	4.3	8.3	9.0	10.9	12.0	.....	7.7	10.5	.....	8.5
Jan. 26..	M.	401	595	540	474	449	543	574	510	476	.....	547	451	.....	502
	S.D.	38	57	40	50	34	44	62	44	60	.....	75	34	.....	49.8
	C.	9.5	9.6	7.4	10.5	7.6	8.1	10.8	8.6	12.6	.....	13.7	7.5	.....	9.8
Feb. 2..	M.	427	566	532	427	449	489	518	487	469	.....	487	430	.....	475
	S.D.	20	53	64	34	21	41	40	43	43	.....	43	45	.....	38.3
	C.	4.7	9.4	12.0	8.0	4.7	8.4	7.7	8.8	9.2	.....	8.8	10.5	.....	8.0
Low-diet av.....	M.	415	597	519	468	445	513	500	523	469	505	474	460	.....	486
	S.D.	33	49	59	42	32	44	52	50	60	48	52	39	.....	45.4
	C.	7.9	8.1	11.3	9.0	7.2	8.8	10.5	9.5	12.8	9.3	10.8	8.5	.....	9.3

subjects and during normal sessions by Dodge and Benedict,[1] who report the average reaction time for a group of normal subjects as 455 σ and the average mean variation[2] about 8.0 per cent of the average latency.

Individual subjects show homogeneous averages from experiment to experiment. For example, with *Kon*, the reaction times range within

[1] Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 106.

[2] Dodge and Benedict use mean variation and not standard deviation which is larger than the former (S. D. =1.253 M. V.). If the 8.0 per cent be multiplied by 1.25 to place it on the same basis with our coefficient of variability, we have 10 per cent to compare with 9.3 for the low-diet research.

TABLE 172.—*Squad B—Time and variability of word reaction.*
[M. in σ; S. D. in σ; and C. in per cent.]

Date.	Reaction.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917.																
Nov. 3..	M.	629	531	559	569	751	.....	498	447	.....	561	537	535	606	451	548
	S.D.	62	44	89	78	103	.....	60	67	.....	61	75	82	81	57	68.9
	C.	9.9	8.3	15.9	13.7	13.7	.....	12.0	15.0	.....	10.9	14.0	15.3	13.4	12.6	12.6
Nov. 17..	M.	591	505	487	549	663	.....	461	395	.....	515	495	476	570	420	507
	S.D.	35	32	43	42	130	.....	48	40	.....	57	63	43	77	47	48.7
	C.	5.9	6.3	8.8	7.6	19.6	.....	10.4	10.1	.....	11.1	12.7	9.0	13.5	11.2	9.7
Dec. 15..	M.	.....	528	503	522	630	.....	433	423	.....	443	483	478	501	443	481
	S.D.	.....	43	40	62	55	.....	24	37	.....	44	48	51	47	33	43.6
	C.	.....	8.2	8.0	11.9	8.7	.....	5.5	8.8	.....	9.9	9.9	10.7	9.4	7.5	9.0
1918.																
Jan. 5..	M.	544	473	472	537	575	634	.....	.....	610	515	492	501	500	423	496
	S.D.	34	36	34	53	41	82	.....	.....	66	44	55	45	34	49	42.7
	C.	6.3	7.6	7.2	9.9	7.1	12.9	.....	.....	10.8	8.6	11.2	9.0	6.8	11.6	8.7
Normal av.	M.	588	509	505	544	655	634	464	422	610	509	502	498	544	434	508
	S.D.	44	39	52	59	82	82	44	48	66	52	60	55	60	47	51
	C.	7.4	7.6	10.0	10.8	12.3	12.9	9.3	11.3	10.8	10.1	12.0	11.0	10.8	10.7	10.0
Jan. 13..	M.	559	514	479	480	.....	542	443	.....	626	487	369	446	475	431	468
	S.D.	49	67	36	30	.....	51	38	.....	37	48	42	40	39	37	42.6
	C.	8.8	13.0	7.5	6.3	.....	9.4	8.6	.....	5.9	9.9	11.4	9.0	8.2	8.6	9.1
Jan. 19..	M.	558	528	478	487	.....	599	440	.....	618	487	419	457	496	427	478
	S.D.	54	43	39	32	.....	51	31	.....	21	39	57	31	56	29	41.1
	C.	9.7	8.1	8.2	6.6	.....	8.5	7.0	.....	3.4	8.0	13.6	6.8	11.3	6.8	8.6
Jan. 27..	M.	556	491	469	477	.....	502	429	.....	602	483	470	457	490	440	476
	S.D.	53	27	31	34	.....	51	37	.....	47	38	63	44	37	33	39.7
	C.	9.5	5.5	6.6	7.1	.....	10.2	8.6	.....	7.7	7.9	13.4	9.6	7.6	7.5	8.3
Low-diet av......	M.	558	511	475	481	.....	548	437	.....	615	486	419	453	487	433	474
	S.D.	52	46	35	32	.....	51	35	.....	35	42	54	38	44	33	411
	C.	9.3	8.9	7.4	6.7	.....	9.4	8.1	.....	5.7	8.6	12.8	8.5	9.0	7.6	8.7

10 per cent of each other. They are, beginning at the first session with this subject (October 27) 550, 506, 514, 505, 506, 501, 540, 532 σ, with a total average of 519 σ and an average variability of 11 per cent.

The results are compared in figure 113, in which curves for both squads and for all three factors of the table, that is, average reaction time, standard deviation, and coefficient of variability, are presented. Squad B shows decidedly more fluctuation from experiment to experiment in the average reaction time than is found with Squad A. They would seem to have done poorly in the first and second trials with this measurement as compared with Squad A, particularly so when it is considered that the data of Squad A, in comparison to that of Dodge and Benedict, show that these men were somewhat slow in these reactions. Squad B did poorly in their last normal experiment (January 5) and on the three low-diet dates made their best records, *i. e.*, 468, 478, and 476. Squad A shows, on the contrary, uniform results up to and including December 19. The two sessions of January 12 and 26 are remarkably poor for this group, being almost at the same level as

their first experiment on word reactions. On February 2 the men returned to the level of their December reaction averages.

The standard deviation was largest for both groups at their first session and fairly uniform beyond that, with the exception of a definite increase for Squad A on January 26. As shown in the lowest pair of curves, the standard deviation is about the same per cent of the average reaction time for both groups. The curves run remarkably close together. As might be expected, the percentage variability was largest at the first, that is, on October 13 and November 3 for Squads A and B. After that it remained between 8 and 10 per cent.

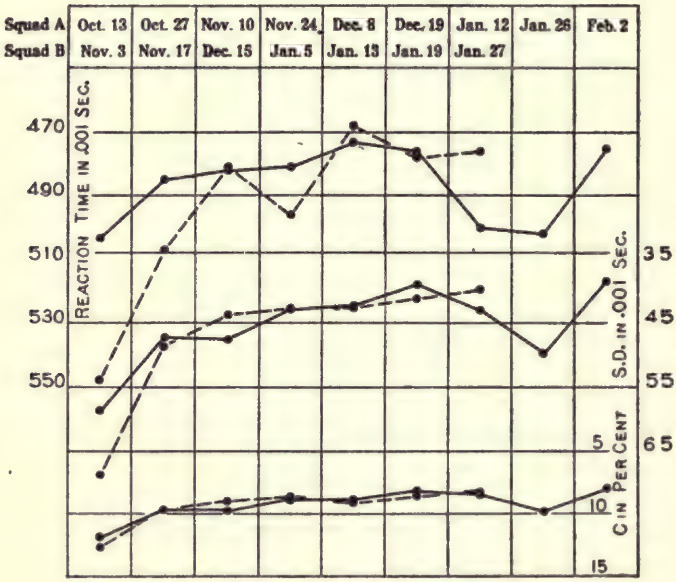

FIG. 113.—Word-reaction time and its variability.
Solid lines represent Squad A, and broken lines Squad B.

The record for January 26 shows a depression. We conclude that the low-diet condition produced no definite change in the general group averages or in the variability of the latency in the word-reaction measurement. In general the results tended to be somewhat poorer following the Christmas vacation.

(11) CONTINUOUS DISCRIMINATION AND REACTION IN FINDING SERIAL NUMBERS.

The total time required to find and point out the numbers 1 to 50 in proper order and without skipping any is shown for both squads in tables 173 and 174. Each squad began this test at their second experimental session, *i. e.*, the second time they came to Boston. There is thus no normal for Squad A. Many of the individual differences between the members of Squad A which were found in the other measurements are also observable here. Obviously, the best scores are

those which represent the shortest time. The best averages for A are for *Bro, Tom,* and *Vea,* with scores of 127, 122, and 132 seconds, respectively. Men who required a conspicuously long time to perform the test were *Spe, Mon,* and *Pec,* who have averages of 183, 168, and 167, respectively. *Spe* did not have so much opportunity for practice as the others. Thus the test brings out the usual individual differences. It required 2 to 3 minutes, the average for all subjects being 147 seconds. Squad B, as shown in table 174, was definitely slower in this test than A, both in the normal and the low-diet averages. Several of the men have average scores of 200 seconds or longer. The normal average is 194 seconds, the low-diet average 178 seconds. While the average of 194 might be considered slow because of the fewer practice occasions and the longer intervals which separated them, this condition does not apply in the three reduction dates, January 13, 19, and 27, which were preceded by ample opportunity for practice. It is therefore clear that the men of Squad B were slower in this test than the subjects in Squad A.

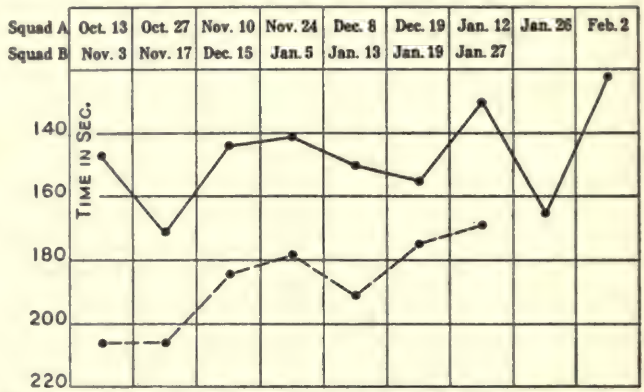

FIG. 114.—Average discriminatory reaction time for finding and pointing to serial numbers.

Solid line curve represents Squad A, and broken curve Squad B.

The averages for both squads on the different dates are compared in figure 114. Squad B is definitely below Squad A; there is somewhat

TABLE 173.—*Squad A—Reaction time for finding serial numbers.*
[Values in seconds.]

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.
1917.														
Oct. 13	111	128	....	124	162	153	182	155	202	215	146	108	160	147
Oct. 27	154	139	201	185	187	185	240	196	154	211	119	150	....	171
Nov. 10	121	172	202	154	105	140	178	131	183	168	124	129	....	144
Nov. 24	116	139	154	146	132	163	191	166	140	162	96	116	....	141
Dec. 8	151	145	147	137	155	205	156	106	177	158	132	132	....	150
Dec. 19	135	154	148	179	134	131	196	167	148	....	150	157	....	155
1918.														
Jan. 12	109	120	146	137	145	117	125	150	173	....	106	116	....	130
Jan. 26	147	161	162	142	155	234	146	220	186	....	131	126	....	165
Feb. 2	101	122	148	133	96	184	112	88	142	....	95	150	....	122
Low-diet average	127	142	164	149	141	168	158	153	167	183	122	132	160	147

TABLE 174.—*Squad B—Reaction time for finding serial numbers.*
[Values in seconds.]

Date.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917															
Nov. 3	204	191	306	175	205	....	218	226	....	186	168	312	118	178	206
Nov. 17	214	192	222	158	152	....	236	221	....	198	240	196	162	239	206
Dec. 15	....	179	269	188	171	....	175	248	....	149	173	206	142	175	184
Jan. 5	206	172	284	129	188	207	....	....	264	193	162	150	134	173	178
Normal average	208	184	270	163	179	207	210	232	264	182	186	216	139	191	194
1918															
Jan. 13	192	138	392	98	....	210	155	....	268	219	180	236	162	137	191
Jan. 19	186	110	216	139	....	192	190	....	251	193	206	213	154	147	175
Jan. 27	181	144	249	161	....	209	155	....	278	133	164	215	144	143	169
Low-diet average	186	131	286	133	....	204	167	....	266	182	183	221	153	142	178

of a practice effect with both groups. Squad A shows a lengthening of time on October 27, also a depression on December 8 and 19, and a marked drop on January 26. Squad B shows a depression in the curve on their first reduction date of January 13. This decline may be a mere coincidence as there is continued improvement on the two following dates, January 19 and 27. In general the curve for Squad B is more regular than that for A, but it can not be stated that there is any definite indication of an effect due to the reduction in diet.

(12) SENSORY THRESHOLD FOR VISUAL EFFICIENCY.

Extended series of observations with this apparatus and with trained subjects have shown that this measure of visual efficiency is remarkably constant from day to day and shows a standard deviation of approximately 4 per cent of the average threshold. The normal series for 1917, previously referred to, contains threshold values for 61 subjects, which range from 38″ to 106″ on the arc of vision. The average was 68.7″, with a standard deviation for the 61 men of 18.5″, which is 27 per cent of the average threshold value. It should be noted that good vision was one of the factors operative in the selection of the normal group of men, 25 of whom (somewhat more than 40 per cent) show thresholds of 60″ or somewhat less.[1] It is something of a sur-

[1] In the test-letters on charts used to determine acuteness of vision, the width of one stroke or of the space between two strokes composing a letter is the fundamental width or unit for vision. A determination of $\frac{20}{20}$ means that the subject distinguishes the direction of lines the stroke width of which occupies 60″ on his arc of vision. Similarly, as recorded on page 175, the width of one dark band or of one light band, or to state it in another way, since the boundary between dark and light is not sharp in our test object (see figure 51), the distance from the center of one dark band to the center of an adjoining light band was taken as the *unit* width in terms of which the visual efficiency was given. A threshold of 60″ signifies that the subject became aware of lines in the test field and could correctly indicate their direction (vertical, horizontal, etc.) when the unit width, from center to center of adjoining dark and light bands equaled 60″ on his arc of vision. In a personal communication Captain Percy W. Cobb, M. R. C., states that workers at the Nela Research Laboratory have regularly employed this same unit with these test objects and believe that the results thus expressed are in closest conformity with the regular Snellen units. Dr. Cobb states further that $\frac{20}{30}$ is quite common as an ophthalmologic finding and that in persons who have no defect or are well corrected, it is not uncommon to get $\frac{20}{15}$ or better, *i. e.*, 45″ or less as visual angles.

prise to find that in the first normal measurement for this threshold on Squad B, the average of the 10 men is 58.2″, that is, 10″ lower than the average for the normal group of prospective aviators, the personnel of which was supposedly selected with some reference to keen vision. Naturally this factor of vision was a matter of pure chance in the selection of the personnel for Squad B. These first averages show almost the same range as the normal series of 1917, that is, the range for B is 41″ to 110″. The latter figure (the record for *Mac*) is not included in the average. If included, it would raise the average somewhat, but not to the level of the average for the normal series of 1917. It is regretted that no normal records are available for Squad A; their first

TABLE 175.—*Squad A—Visual efficiency and its mean variation.*
[Values given in seconds on the arc of vision.]

Date.	Acuity.	Bro.	Can.[1]	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.[1]	Vea.	Fre.	Av.
1917.															
Oct. 13..	M.	94	108	.....	43	104	91	56	133	86	42	89	58	100	86.2
	M. V.	5.3	13.3	.....	3.9	9.6	5.3	6.0	21.5	8.4	1.9	11.9	5.1	7.2	9.03
Oct. 27..	M.	47	76	71	46	99	83	74	90	87	41	80	51	.....	73.3
	M. V.	4.5	[2]31.0	7.6	6.9	9.3	6.5	7.2	10.9	7.4	2.6	11.9	6.8	.....	10.24
Nov. 10..	M.	43	91	69	46	103	89	77	101	80	[3]37	83	47	.....	76.0
	M. V.	4.1	[2]20.0	10.7	4.3	6.3	5.3	7.6	15.3	6.2	2.8	11.9	3.2	.....	8.42
Nov. 24..	M.	40	77	73	45	100	76	84	93	81	37	82	45	.....	72.3
	M. V.	3.0	[2]30.0	5.6	2.6	5.9	8.2	5.0	13.1	5.8	2.5	13.0	4.2	.....	9.08
Dec. 8..	M.	41	81	75	41	91	68	86	105	86	36	78	44	.....	72.1
	M. V.	2.6	[2]26.0	9.0	2.3	8.1	3.4	8.4	19.0	5.5	3.6	12.5	2.7	.....	9.05
Dec. 19..	M.	42	68	75	43	88	67	83	68	78	.....	76	50	.....	66.3
	M. V.	3.6	27.3	6.2	3.0	4.1	7.6	6.6	9.3	8.1	.....	11.0	6.2	.....	8.68
1918.															
Jan. 12..	M.	38	75	80	41	87	76	75	85	77	.....	76	42	.....	67.2
	M. V.	2.0	22.0	3.7	3.2	4.7	8.7	6.2	9.6	6.4	.....	11.8	5.4	.....	8.00
Jan. 26..	M.	36	68	68	42	90	65	68	78	84	.....	71	40	.....	64.2
	M. V.	1.3	27.0	6.0	1.4	5.0	5.5	6.7	8.0	8.4	.....	10.1	2.5	.....	7.59
Feb. 2..	M.	36	75	69	41	91	74	86	62	78	.....	69	39	.....	65.1
	M. V.	1.4	24.8	6.1	1.8	4.0	3.2	8.4	23.0	6.7	.....	6.4	5.5	.....	8.52
Low-diet av.....	M.	46.3	79.9	72.5	43.1	94.8	76.6	76.6	90.6	81.9	38.6	78.2	46.2	100.0	71.4
	M. V.	3.1	24.6	6.9	3.3	6.3	6.0	6.9	14.4	7.0	2.7	11.2	4.6	7.2	8.73

[1] Subject commonly wore glasses but not when tested.
[2] In the vertical axis *Can* has a threshold of about 48″; it is his pronounced astigmatism, therefore, that accounts for large M. V. of this subject.
[3] The subject's father was a visitor in the room when these measurements were taken.

measurement for this threshold was on October 13; this was the first observation after food reduction, which began on October 4. The average for the 10 men on this date is 86.2″, and would not be materially different if *Spe* and *Fre* were included. According to the only available normals, this seems to be high.

The individual values in tables 175 and 176 are, in each case, the average of from 12 to 20 threshold determinations, distributed about equally between the four axes which were used, as outlined on page 175. The mean variation computed by taking all of an individual's

observations on one evening and considering them as one group, is partly a measure of astigmatism as well as of true variability. The number of observations made at each axis was too small for satisfactory determination of a separate mean or standard deviation. The average mean variation, so-called, is found to be 8.7″ for Squad A (see lower right-hand corner of table 175). It is somewhat smaller in the case of Squad B, being 5.3″ for their normal measurements and 4.8″ for their low-diet averages. (See table 176.)

TABLE 176.—*Squad B—Visual efficiency and its mean variation.*
[Values given in seconds on the arc of vision.]

Date.	Acuity.	Fis.	Har.	How.	Ham.	McM.[1]	Kim.	Lon.	Mac.[2]	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917.																
Nov. 3..	M.	50	52	41	46	67	.....	57	110	.....	79	78	68	51	60	58.2
	M. V.	2.3	2.9	2.6	3.7	4.2	.....	5.8	10.5	.....	9.2	12.5	4.4	3.3	6.3	5.30
Nov. 17..	M.	44	84	63	45	62	.....	83	97	.....	85	45	80	47	72	64.8
	M. V.	3.1	8.7	6.8	3.3	5.1	.....	9.4	7.7	.....	5.0	3.4	7.8	5.8	6.2	5.95
Dec. 15..	M.	.....	78	41	41	55	.....	72	88	.....	84	82	87	42	60	65.2
	M. V.	.....	9.3	1.7	1.9	5.7	.....	5.5	7.5	.....	8.4	5.3	3.7	5.2	8.6	5.51
1918.																
Jan. 5..	M.	44	81	49	[3]45	64	([4])	.....	.....	89	91	46	91	43	58	61.0
	M. V.	2.8	9.8	3.5	1.6	5.7	.....	.....	.....	6.5	5.3	2.9	3.7	5.3	4.4	4.37
Normal av.	M.	46.0	73.8	48.5	44.3	62.0	.....	70.7	98.3	89.0	84.8	62.8	81.5	45.8	62.5	62.3
	M. V.	2.7	7.7	3.7	2.6	5.2	.....	6.9	8.6	6.5	7.0	6.0	4.9	4.9	6.4	5.28
Jan. 13..	M.	40	90	43	40	.....	64	70	.....	81	78	70	83	42	67	62.3
	M. V.	2.2	4.9	9.7	7.2	.....	7.8	6.1	.....	4.9	5.5	8.6	7.6	2.5	7.6	6.19
Jan. 19..	M.	41	80	38	36	.....	53	74	.....	83	89	38	84	40	61	58.1
	M. V.	1.5	6.3	1.8	2.8	.....	4.4	4.7	.....	5.8	6.4	2.9	5.5	1.7	5.2	3.88
Jan. 27..	M.	40	74	39	44	.....	54	72	.....	86	83	[5]32	79	40	62	56.5
	M. V.	1.9	4.0	3.4	7.9	.....	4.6	4.5	.....	7.0	6.1	1.9	4.6	3.5	4.0	4.18
Low-diet av......	M.	40.3	61.3	40.0	40.0	.....	57.0	72.0	.....	83.3	83.3	46.7	82.0	40.7	63.3	59.0
	M. V.	1.9	5.1	5.0	6.0	.....	5.6	5.1	.....	5.9	6.0	4.5	5.9	2.6	5.6	4.75

[1] Subject commonly wore glasses but not when tested.
[2] The right eye was used in the test as with the other subjects, but *Mac* informs us that he has better vision with his left eye.
[3] *Ham* complained that his eyes were tired from reading on the train while coming to Boston.
[4] This was the first session for *Kim* and this measurement was not given for lack of time.
[5] *Sne* said he could see the fixation dot better in this test than in any previous experiment.

In figure 115 the mean variations (see the two lower curves) are very consistent from experiment to experiment, with a slight increase for Squad B at the time of the first reduction date (January 13). The curve for Squad A is definitely and consistently below that for Squad B, with two slight depressions on October 27 and November 24 and a tendency to smaller variations near the close of the series of experiments, but these fluctuations are certainly not larger than might normally occur.

The average thresholds for the two groups, as expressed in degrees on the arc of vision and shown in the upper curves in figure 115, maintain from October 27 and November 17 about the same relative levels

with continuous improvement. The wide and opposed variations in the thresholds shown by the two squads at their first measurements cannot be satisfactorily explained. In the case of Squad B, the rise in the threshold, shown on November 17, is of course partly due to the records for *Har*, *How*, and *Lon*, as shown in table 176. However, the average threshold does not improve on December 15, but is, in fact, slightly higher on this date, for some of the subjects, particularly *Sne*, show an increase. Considering Squad B's successive averages for November 17, December 15, January 5, and January 13, it seems very probable that the average threshold for November 3, the first time this measurement was taken, is very low for some chance reason which is not revealed. This conclusion seems further justifiable in view of the fact that this threshold for Squad B, as was pointed out earlier, is below the average for the normal group of 1917.

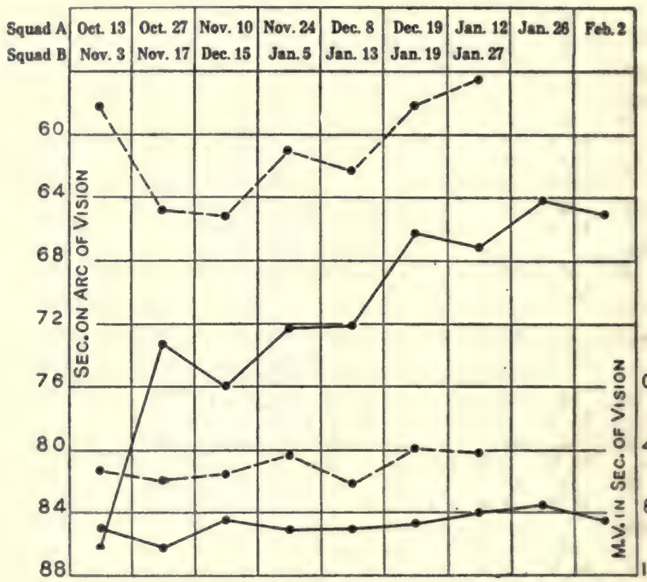

Fig. 115.—Visual efficiency and its mean variation. Solid lines represent Squad A, and broken lines Squad B.

With Squad A the first average threshold is very high, and indeed, by present standards, seems abnormally high. It is of course associated with food reduction, although on this particular date (October 13) the subjects received an average of 1,993 net calories per man, an amount which was 250 calories above the average for the 9 days during the low-diet period on which the subjects of Squad A came to Boston. An examination of table 175 for Squad A would indicate that this high threshold for October 13 is due principally to the subjects *Pea*, *Can*, and *Bro*. The first designated subject was poor in threshold measurements, as will be seen by examining his record for the electrical threshold. *Can* commonly wore glasses and apparently found some difficulty in adjusting himself to taking the test without them. No explanation can be given for the relatively high threshold of *Bro*, who later in the series showed very consistent results and also a very low threshold; furthermore his mean variation was usually small,

the average being 3.1 seconds. The higher threshold for October 13 may be partly due to the food reduction. The poor result for November 10 corresponds with the lowest average net energy figure for any of the experimental dates (see table 146). These correspondences do not definitely prove that the reduced diet raised the threshold for visual efficiency with Squad A, and as the results for B give no clear substantiation, the findings appear to be negative. The difference in level between the two squads can hardly be assigned as a low-diet effect, although if each squad were several times larger, this might be significant.

(13) SENSORY THRESHOLD FOR ELECTRIC SHOCK.

This measurement taken in the same way and employing the same apparatus, with the exception of the electrodes,[1] was used in the normal series of 1917. The threshold range shown by the 63 normal men was from 46 to 195 volts. The subjects were distributed in threshold ranges as follows:

50 or below.	51 to 75.	76 to 100.	101 to 125.	126 to 150.	151 to 175.	176 to 200.
1	3	13	23	16	5	2

The distribution is seen to be a fairly normal one, the mode is clearly at 101 to 125 volts, within which range 23 of the subjects came. The average for the whole group was 117.3 volts, with a standard deviation for the series of 63 subjects of 30 volts.

With the above values in mind as normals for initial measurements, we may turn to a consideration of the data for Squads A and B, as shown in tables 177 and 178. For the first experiment, September 29, the 10 men of Squad A show an average of 118 volts as compared to 117 volts for the normal series of 1917. That this close correspondence is not entirely accidental is proved by the fact that *Kon*, *Spe*, and *Fre* of Squad A, whose values are not included in the average, show a similar average of 123 volts. The 10 men of Squad B in their first experiment had an average of 126 volts, the one man whose records are not in the average (*Mac*) having a value of 101 volts. It appears that in initial measurements of the threshold for electric shock, with the apparatus and technique here employed, a normal average value of about 120 volts may be reasonably expected. Squad A (see table 177) for the nine experiments of October 13 to February 2, has also a total average for the ten men of exactly 120 volts, suggesting that there has been very little, if any, improvement in contrast to the visual threshold results throughout the period of measurements. The averages for the individual subjects, exclusive of September 29, range from 69 volts for *Moy* to 172 volts for *Mon*.

[1]The electrodes were also of the non-polarizable type, but separate vessels were provided for each finger; the vessels being quite small, the level of the solution was adjusted for each subject. The normal measurements were made in the summer and the salt solution was of room temperature. It was unnecessary to warm it by the electric heater.

TABLE 177.—*Squad A—Electrical threshold and its variability.*
[M. and S. D. in volts; C. in per cent.]

Date.	Threshold.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.
1917.				Oct. 6											
Sept. 29..	M.	90	126	137	123	133	143	77	136	120	129	125	109	102	118
	S.D.	6.3	8.0	2.8	3.5	2.8	4.0	2.8	5.3	2.8	6.9	4.0	5.7	12.3	4.5
	C.	7.0	6.3	2.0	2.8	2.1	2.8	3.6	3.9	2.3	5.3	3.2	5.2	12.1	3.9
Oct. 13..	M.	114	151	.....	150	129	210	113	52	208	96	113	136	102	138
	S.D.	3.5	4.5	.....	7.2	5.7	6.3	4.5	8.5	4.0	2.8	6.3	9.4	6.0	6.0
	C.	3.1	3.0	.....	4.8	4.4	3.0	4.0	16.3	1.9	2.9	5.6	6.9	5.9	5.3
Oct. 27..	M.	101	116	132	110	133	191	76	105	119	120	85	110	.....	115
	S.D.	2.8	7.5	4.0	9.8	7.2	15.1	6.0	9.4	11.5	7.2	11.7	11.0	.....	9.2
	C.	2.8	6.5	3.0	8.9	5.4	7.9	7.9	8.9	9.7	6.0	13.8	10.0	.....	8.2
Nov. 10..	M.	108	131	149	108	118	154	57	105	139	49	141	123	.....	118
	S.D.	2.8	8.9	5.3	9.2	8.0	8.9	5.3	9.8	8.9	4.5	3.5	6.9	.....	7.2
	C.	2.6	6.8	3.6	8.5	6.8	5.8	9.3	9.3	6.4	9.2	2.5	5.6	.....	6.4
Nov. 24..	M.	99	145	140	101	112	182	64	96	118	97	155	171	.....	124
	S.D.	4.9	12.8	4.5	3.5	5.3	14.7	4.0	10.4	11.5	8.2	7.2	7.8	.....	8.2
	C.	5.0	8.8	3.2	3.5	4.7	8.1	6.3	10.8	9.7	8.5	4.6	4.6	.....	6.6
Dec. 8..	M.	116	122	114	106	78	182	73	88	104	116	142	145	.....	116
	S.D.	7.2	7.8	12.2	9.2	9.4	9.2	3.5	9.8	7.2	9.8	5.7	7.8	.....	7.7
	C.	6.2	6.4	10.7	8.7	12.1	5.1	4.8	11.1	6.9	8.4	4.0	5.4	.....	7.1
Dec. 19..	M.	110	123	155	121	140	167	46	120	124	.....	90	132	.....	117
	S.D.	3.5	4.5	4.9	4.5	11.0	8.2	2.8	20.0	12.5	.....	9.2	9.8	.....	8.6
	C.	3.2	3.7	3.2	3.7	7.9	4.9	6.1	16.7	10.1	.....	10.2	7.4	.....	7.4
1918.															
Jan. 12..	M.	125	103	149	115	108	152	54	83	162	.....	123	132	.....	116
	S.D.	6.6	3.5	5.3	4.9	6.3	7.2	4.9	4.9	4.0	.....	4.5	9.6	.....	5.6
	C.	5.3	3.4	3.6	4.3	5.8	4.7	9.1	5.9	2.5	.....	3.7	7.3	.....	5.2
Jan. 26..	M.	108	135	134	143	101	137	65	136	100	.....	88	130	.....	114
	S.D.	7.8	5.3	3.5	6.9	2.8	6.6	2.0	7.8	10.4	.....	16.8	7.2	.....	7.4
	C.	7.2	3.9	2.6	4.8	2.8	4.8	3.1	5.7	10.4	.....	19.1	5.5	.....	6.7
Feb. 2..	M.	84	157	111	131	136	177	76	111	144	.....	115	113	.....	122
	S.D.	3.2	4.9	15.4	7.2	5.3	4.9	5.3	16.8	9.4	.....	4.9	6.9	.....	6.9
	C.	3.8	3.1	13.9	5.5	3.9	2.8	7.0	15.1	6.5	.....	4.3	6.1	.....	5.8
Low-diet av.....	M.	107	131	136	121	117	172	69	100	135	96	117	132	102	120
	S.D.	4.7	6.6	6.9	6.9	6.9	9.1	4.3	10.8	8.8	6.5	7.7	8.5	6.0	7.4
	C.	4.3	5.1	5.5	5.9	6.0	5.2	6.4	11.1	7.1	7.0	7.5	6.5	5.9	6.5

The average individual threshold determinations for the members of Squad B demonstrate no peculiarity which differentiates them from the values which have been discussed for A. The group average for the 5 normal experiments is 115 volts as compared to the value of 126 volts for the first session. This indicates some improvement. The average for the 3 low-diet experiments is 123 volts, which is fairly close to the average for the first experiment.

In connection with these threshold averages, and more particularly with the variability values, a matter of experimental procedure deserves consideration. In the electrical-threshold determination it was desirable to secure an average, if possible, that had statistical significance. With this apparatus, stimuli could be presented about every 2.5 seconds. If one began at a value which was easily felt and proceeded with the series by decreasing the voltage carefully in small steps to that which was the threshold value, it required about 1 minute

TABLE 178.—*Squad B—Electrical threshold and its variability.*

[M. and S. D. in volts; C. in per cent.]

Date.	Thresh-old.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917.																
Oct. 6..	M.	228	133	92	124	.....	.....	164	101	.....	110	89	77	126	116	126
	S.D.	4.0	2.8	2.8	2.8	.....	.....	2.0	5.7	.....	0.0	4.0	2.8	2.0	2.8	2.6
	C.	1.8	2.1	3.0	2.3	.....	.....	1.2	5.6	.....	0.0	4.5	3.6	1.6	2.4	2.3
Nov. 3..	M.	164	126	89	135	109	.....	122	107	.....	106	95	75	127	109	115
	S.D.	10.0	6.6	4.0	6.6	4.5	.....	8.2	3.5	.....	4.5	4.9	8.5	9.6	2.8	6.6
	C.	6.1	5.2	4.5	4.9	4.1	.....	6.7	3.3	.....	4.2	5.2	11.3	7.6	2.6	5.8
Nov. 17..	M.	189	134	76	144	113	.....	123	90	.....	87	94	79	145	98	117
	S.D.	4.0	4.9	3.5	4.0	4.9	.....	6.0	3.5	.....	4.5	5.7	4.0	6.3	2.8	4.6
	C.	2.1	3.7	4.6	2.8	4.3	.....	4.9	3.9	.....	5.2	6.1	5.1	4.3	2.9	4.2
Dec. 15..	M.	.....	124	104	128	84	.....	129	83	.....	83	87	93	135	104	110
	S.D.	.....	6.3	2.8	4.0	8.7	.....	4.9	4.0	.....	7.8	9.6	4.5	11.8	6.0	6.4
	C.	.....	5.1	2.7	3.1	10.4	.....	3.8	4.8	.....	9.4	11.0	4.8	8.7	5.8	6.0
1918.																
Jan. 5..	M.	185	120	73	134	120	.....	.....	.....	193	120	73	104	146	106	118
	S.D.	9.4	4.0	3.5	6.6	13.0	.....	.....	.....	6.0	7.2	12.0	4.5	7.8	2.8	6.4
	C.	5.1	3.3	4.8	4.9	10.8	.....	.....	.....	3.1	6.0	16.4	4.3	5.3	2.6	5.9
Normal av......	M.	192	127	87	133	107	.....	135	95	193	101	88	86	136	107	115
	S.D.	6.9	4.9	3.3	4.8	7.8	.....	5.3	4.2	6.0	4.8	7.3	4.9	7.5	3.4	5.3
	C.	3.8	3.9	3.9	3.6	7.4	.....	4.2	4.4	3.1	4.6	8.6	5.8	5.5	3.3	4.8
Jan. 13..	M.	176	112	105	150	.....	97	121	.....	207	127	59	77	149	125	120
	S.D.	10.0	4.5	4.5	4.5	.....	4.5	14.7	.....	15.7	7.8	7.5	4.0	7.5	4.5	7.0
	C.	5.7	4.0	4.3	3.0	.....	4.6	12.1	.....	7.6	6.1	12.7	5.2	5.0	3.6	6.2
Jan. 19..	M.	207	152	92	162	.....	108	135	.....	141	108	118	80	161	147	136
	S.D.	5.7	7.2	4.5	7.2	.....	4.9	3.5	.....	6.3	9.2	5.3	3.5	14.6	7.5	6.8
	C.	2.8	4.7	4.9	4.4	.....	4.5	2.6	.....	4.5	8.5	4.5	4.4	9.1	5.1	5.1
Jan. 27..	M.	158	108	109	120	.....	100	121	.....	158	100	99	75	124	123	114
	S.D.	8.7	11.3	3.5	8.2	.....	4.0	5.7	.....	11.8	6.3	6.0	4.9	12.6	8.0	7.5
	C.	5.5	10.5	3.2	6.8	.....	4.0	4.7	.....	7.5	6.3	6.1	6.5	10.2	6.5	6.6
Low-diet av......	M.	180	124	102	144	.....	102	126	.....	169	112	92	77	145	132	123
	S.D.	8.1	7.7	4.2	6.6	.....	4.4	8.0	.....	11.3	7.8	6.3	4.1	11.6	6.7	7.1
	C.	4.7	6.4	4.1	4.7	.....	4.4	6.5	.....	6.5	7.0	7.8	5.4	8.1	5.1	6.0

to reach and pass the threshold. Thus, at best, in the time available not more than 5 to 8 test series could be given. This is a somewhat small number to average. In supplement of the description of procedure, given on page 176, it should be made clear that following a preliminary series to determine the approximate value of the threshold, series lasting about 2 minutes were taken very near the threshold level with an effort to get as many responses in this vicinity as possible. The voltage was increased and decreased very gradually. If the subject responded two or three times in succession the voltage was gradually decreased to a point where he failed. If he failed to respond to two or three shocks which came through to his fingers, the voltage was gradually increased. In other words, a large number of shocks in increasing and decreasing series were given in succession. The subject, realizing that the shocks were all to be very close to his limit, concentrated his attention at those moments when the shock might be expected and responded to every one which he felt. The voltage

of every shock with response or failure to respond was recorded. In elaborating the records, the average between successive voltage records when the subject responded in one case and in the next case failed to respond, was arbitrarily considered a threshold determination. For example: if a man responded to a shock voltage of 104 volts and had been responding to shocks of this strength, or stronger, and then failed to respond to a shock of 100 volts, the threshold determination was considered the average of 104 and 100, or 102 volts. Usually about 20 such determinations would occur in the records taken with a subject in the test period of one evening.

The average standard deviation for the individual series of determinations on a single subject (see tables 177 and 178) is about 7.5 volts. There are rather wide variations from this, that is, with Squad A they range from 2 to 20 volts. *Pea* has the largest average standard deviation (10.8 volts) of any man in Squad A. The smallest is consistently found with *Moy* (4.3 volts), whose threshold was also the lowest average for the group. *Van* and *Sch*, of Squad B, have standard deviations of 11.6 and 11.3 volts, as averages for the reduction period. Their thresholds were, however, much higher than that for *Pea*, being 145 and 169 volts, as compared with 100 volts. The standard deviation is usually about 6.5 per cent of the average threshold value. Squad B show slightly less than this, particularly in the average for the five normal experiments, the percentage for which is 4.8. The exceptional case, in the two squads, is that of *Pea* in Squad A, with an average coefficient of variability of 11.1 per cent for the low-diet period. It is exceptional to find any other of the 25 subjects who comprised these two squads showing a variability of as much as 10 per cent on any date. The small average variability of both squads in their first experiment is due to the much smaller number of threshold determinations that were made on these dates, when the method was not the same as described in the paragraph above, but was identical with that used in the normal series of 1917. The small variability within any individual series of threshold determinations makes this measurement compare very favorably with any sensory threshold measurement with which we are familiar.

The fluctuations of the two sets of results throughout the group of experiments are shown in figure 116. First it may be noted that the standard deviation and coefficient of variability are practically stationary from first to last and are at very nearly the same level for both squads, tending to be a little smaller with Squad B. There is a slight increase in the standard deviation for October 27, Squad A, apparently due to unusually large deviations with *Tom*, *Vea*, *Pec*, and *Mon*. Both squads show one marked depression (higher threshold) during the period of the experiment. In the case of A this occurred at the first reduction date, October 13, when the average was

138 volts, as compared to the former average threshold of 118 volts, a rise in the threshold of 17 per cent; this change is three times as large as the average standard deviation. Seven of the 10 subjects show in their averages this change to a higher threshold at the time of the second experiment. It is of interest to compare this high electrical threshold on October 13, the first experiment after food reduction began, with the high visual threshold on the same date. (See figure 115.) There are two much smaller depressions in the curve, that is, on November 24 and February 2, but in general, a very even level obtains which is near that of the first and normal (September 29) experiment. Squad B began high at 126 volts, for October 6, which was largely due to the abnormally high threshold found for *Fis* of 228 volts. This was a value higher than any found among the 63 normal subjects of the

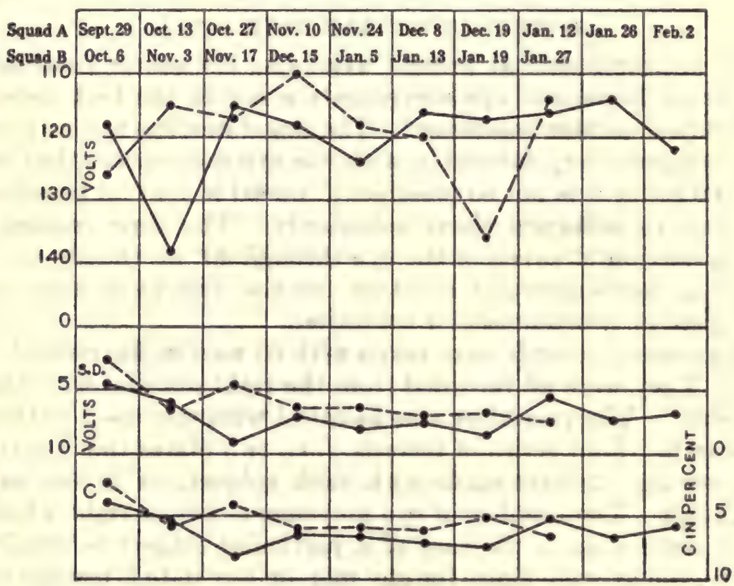

FIG. 116.—Electrical threshold averages and variability.
Solid line curves represent Squad A, and broken curves Squad B.

series of 1917 and considerably higher than succeeding values with this subject, although his general average is in the neighborhood of 190 volts, the limit of the supposedly normal range. Hence it seems that the improvement shown between the first and second experiments is partly to be discounted as an individual peculiarity. The date of January 5 has previously been noted in other measurements as showing results for Squad B somewhat below their average. The first two experiments during the low-diet period of Squad B, particularly the second one, show a markedly higher electrical threshold than even that of January 5, which is itself higher than that for the three

previous dates. The change is very similar to that which occurred in the second experiment with Squad A. On the last date for Squad B, January 27, the normal level was reached, but Squad A was not quite at their normal level in the last experiment.

The data with both squads appear to indicate that, coincident with the beginning of food reduction, the electrical threshold was increased in the neighborhood of 15 per cent, while the standard deviation and percentage of variability show no concomitant change. Threshold determinations on Squad B indicate what might reasonably be expected, *i. e.*, some improvement with practice. It would be surprising if the physiological threshold were reached without practice in this case of electrical stimulation. Squad A shows no such improvement with practice, and this lack we associate with the reduced diet.

(14) SPEED OF THE EYE MOVEMENTS.

Of the measurements at present available, the motor coordination for successive horizontal eye movements is one of the best ndicators of the neuro-muscular condition.[1] The finger movements, as a motor process, compare very favorably with the eye movements, but in the case of the latter it is not so possible, if indeed it is at all possible, for the subject to influence them voluntarily. The time required for making a horizontal sweep of the eye through 40° on the arc of vision is almost a neuro-muscular constant for the individual and for his physiological or neuro-muscular condition.

Eye-movement records were taken with 63 men in the normal series of 1917. They were all recorded from the right eye and with the left eye covered.[2] The procedure was identical with that used in the low-diet research. Four series of records, *i. e.*, two plates (for illustrative records, see fig. 52) were made with each subject, as in the present investigation. The number of eye movements left or right which are available for counts in the case of a particular subject is usually 20. Therefore, the average figure for any man on any date is usually drawn from this number of counted movements. The range of eye-movement speed shown by the men in the normal series of 1917 is tabulated in table 179. The units are 0.001 second (σ) and the column headings in the table are self-explanatory. Two subjects show speeds for movements to the left which average 76 and 79 σ, respectively. These fall in the group division 71 to 80. The slowest eye-movement times for left movement were the averages 141 and 148. The distribution between these high and low points is fairly characteristic of normal frequency. The mode is clearly at 101 to 110, 24 of the 63 subjects showing averages which came within this range. The total average for the left movement is 107.0 σ and the standard deviation for the

[1]Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, pp. 146 and 262.
[2]There were a very few exceptions to this latter statement due to errors in the procedure.

series of 63 left movement averages is 13.9 σ, showing a coefficient of variability within the group of 13 per cent. The movements to the right fall within a narrower range than those for the left. The average fastest speed is 75, and the slowest 128. The distribution between these extremes is sensibly normal, the mode occurring at 91 to 100. The average for the whole series of 63 individual averages is 97.8 σ. The standard deviation is 11.7 σ and the coefficient of variability for movements right therefore equals 12 per cent.

The measurements taken on the normal subjects during normal experiments by Dodge and Benedict in connection with their alcohol investigation gave the following results as averages of the first normal series for 7 subjects: Speed for movements to the left, 101 σ; for movements to the right 99 σ. There is fair agreement between these totally different groups of individuals.

With the subjects used by Dodge and Benedict, the eye movements were taken in the afternoon and evening. In the case of the normal series of 1917 the time of day was always between 7 and 10 p. m. and following a hearty supper. The measurements with the subjects on reduced diet were invariably taken in the morning and following the light breakfast at the Laboratory. The eye reactions and eye movements were successive measurements.

TABLE 179.—*Range of eye-movement speeds shown by a group of 63 normal men, series of 1917.*

[Records taken from the right eye and with the left eye covered.]

Speed ranges for 40° movements, time unit 0.001 sec.	Distribution of 63 subjects.	
	Movements left.	Movements right.
61 to 70	0	0
71 to 80	2	4
81 to 90	4	15
91 to 100	14	19
101 to 110	24	16
111 to 120	9	7
121 to 130	6	2
131 to 140	2	0
141 to 150	2	0

The average results for Squads A and B are given in tables 180 and 181. We have no normal records for Squad A. The first three dates, that is, November 4, 18, and December 16, for Squad B are normal in the sense that the diet had not then been reduced. November 4 (see table 181) shows an average for movements to the left of 95.1 σ, and for movements to the right of 88.9 σ. The time required for movements of 40° to the left, registration being from the right eye and with the left eye covered, is noted to be longer than similar movements to the right. As this is seen to be characteristic of the records for the low-diet research, it is prominent also in the averages of the normal series of 1917, and moreover in the normal records taken by Dodge and Benedict. The reason for this discrepancy between the time requirement for right and left movement can not be definitely assigned at this time. We have considerable data on the problem and it is under investigation at the Nutrition Laboratory. The averages for

left and right are, as in the case of the normal data of Dodge and Benedict, somewhat below the values shown for the 63 men of the series of 1917. This may be a mere matter of chance, or on the other hand partly due to the time of day of taking the records. Undoubtedly sleepiness slows down the eye movements.[1] The variability in the

TABLE 180.—*Squad A—Eye movement speed and its variability.*

[L. and R. designate left and right movements, M. and S. D. in σ, and C. in per cent.]

Date.	Eye.	Speed.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av.
1917.															
Oct. 28...	L.	M.	97	94	94	112	84	102	99	93	91	99	97	97	96.6
		S.D.	6.1	4.5	8.1	11.5	5.0	7.8	7.9	9.1	5.9	7.9	10.1	3.2	7.1
		C.	6.3	4.8	8.6	10.3	5.9	7.6	8.0	9.8	6.5	8.0	10.4	3.3	7.3
	R.	M.	96	88	76	100	90	103	86	88	96	114	95	89	93.1
		S.D.	5.8	4.1	5.8	6.1	4.2	11.3	8.4	4.2	4.8	9.9	6.1	6.5	6.2
		C.	6.0	4.7	7.6	6.1	4.7	11.0	9.8	4.8	5.0	8.7	6.4	7.3	6.6
Nov. 25...	L.	M.	96	88	99	114	92	109	97	99	111	124	106	100	101.2
		S.D.	7.4	5.8	11.9	10.9	6.7	6.9	8.3	8.6	11.8	15.2	12.9	8.1	8.7
		C.	7.7	6.6	12.0	9.6	7.3	6.3	8.6	8.7	10.6	12.3	12.2	8.1	8.6
	R.	M.	103	80	80	93	95	98	78	92	92	113	100	90	92.1
		S.D.	8.4	4.9	6.1	6.4	6.2	8.4	7.4	8.1	8.5	15.0	9.5	11.1	7.9
		C.	8.2	6.1	7.6	6.9	6.5	8.6	9.5	8.8	9.2	13.3	9.5	12.3	8.6
Dec. 9...	L.	M.	107	94	95	108	87	98	101	95	119	128	107	101	101.7
		S.D.	9.9	4.5	11.3	14.4	6.9	11.6	8.4	9.6	15.7	14.8	10.3	10.0	10.1
		C.	9.3	4.8	11.9	13.3	7.9	11.8	8.3	10.1	13.2	11.6	9.6	9.9	9.8
	R.	M.	104	84	77	95	92	98	83	84	105	125	106	87	93.8
		S.D.	8.6	5.4	5.9	5.8	8.2	5.8	7.4	4.2	18.9	17.0	17.4	5.6	8.7
		C.	8.3	6.4	7.7	6.1	8.9	5.9	8.9	5.0	18.0	13.6	16.4	6.4	9.0
1918.															
Jan. 13...	L.	M.	104	87	93	120	92	107	106	96	114	.....	98	108	103.2
		S.D.	8.8	6.8	11.0	14.9	9.5	8.8	11.3	8.4	12.5	.....	11.5	9.5	10.2
		C.	8.5	7.8	11.8	12.4	10.3	8.2	10.7	8.8	11.0	.....	11.7	8.8	9.8
	R.	M.	101	79	75	94	99	102	85	86	102	.....	91	91	93.0
		S.D.	8.1	3.0	5.8	5.5	10.5	12.3	10.7	7.4	11.7	.....	10.1	6.8	8.6
		C.	8.0	3.8	7.7	5.9	10.6	12.1	12.6	8.6	11.5	.....	11.1	7.5	9.2
Jan. 27...	L.	M.	106	87	100	131	98	107	109	101	107	.....	105	104	105.5
		S.D.	9.6	7.7	14.0	16.5	9.1	11.0	10.7	8.1	9.2	.....	14.3	9.6	10.6
		C.	9.1	8.9	14.0	12.6	9.3	10.3	9.8	8.0	8.6	.....	13.6	9.2	9.9
	R.	M.	106	81	75	102	101	96	87	88	99	.....	98	85	94.3
		S.D.	8.1	4.8	6.6	9.3	9.8	5.7	8.8	7.7	7.4	.....	7.6	8.1	7.7
		C.	7.6	5.9	8.8	9.1	9.7	5.9	10.1	8.8	7.5	.....	7.8	9.5	8.2
Low-diet av......	L.	M.	102.0	90.0	96.2	117.0	90.6	104.6	102.4	96.8	108.4	117.0	102.6	102.0	101.6
		S.D.	8.4	5.9	11.3	13.6	7.4	9.2	9.3	8.8	11.0	12.6	11.8	8.1	9.3
		C.	8.2	6.6	11.7	11.6	8.1	8.8	9.1	9.1	10.0	10.6	11.5	7.9	9.1
	R.	M.	102.0	82.4	76.6	96.8	95.4	99.4	83.8	87.6	98.8	117.3	98.0	88.4	93.3
		S.D.	7.8	4.4	6.0	6.6	7.8	8.7	8.5	6.3	10.3	14.0	10.1	7.6	7.8
		C.	7.6	5.4	7.9	6.8	8.1	8.7	10.2	7.2	10.2	11.9	10.2	8.6	8.3

eye-movement records shown with Squad B, November 4, is slightly above 8 per cent as an average for the variability figures of the individual series. Individual subjects show variabilities which range from 4 per cent with *Lon*, left, to 12.7 per cent with *How*, left.

[1]From a totally different series of experiments we have records on one subject who, when the records were taken, was very sleepy and his eye movement time for 40° movements is in the range of 280 to 300; he started the series of movements at the signal from the operator, but the plate shows that he very soon closed his eyes and was asleep.

On the average for the 3 days, November 4, 18, and December 16, the men of Squad B have average eye movement time which, in the case of movements left, ranges from 88.0 to 117.5 σ, *Sne* and *Fis*. The average for all is 96.3 σ, the average variability 8.3 per cent. In the case of movements right the range is from 81.7 to 104.5 σ for *How* and *Fis*, respectively. The average for the 10 subjects usually discussed is 89.3 σ, the variability 8.6 per cent. Thus the members of Squad B show no values which are on the one hand as small, or on the other as large, as the limiting ranges of the group of 1917.

TABLE 181.—*Squad B—Eye movement speed and its variability.*

[L. and R. designate left and right movements, M. and S. D. in σ, and C. in per cent.]

Date.	Eye.	Speed.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917. Nov. 4	L.	M.	116	87	86	98	96	.....	99	108	.....	90	90	93	98	94	95.1
		S.D.	9.4	9.3	7.2	7.2	7.6	.....	4.0	8.4	.....	6.9	8.7	6.9	6.9	10.2	7.7
		C.	8.1	10.7	8.4	7.4	7.9	.....	4.0	7.8	.....	7.7	9.7	7.4	7.0	10.9	8.1
	R.	M.	102	85	82	93	97	.....	93	87	.....	81	82	90	92	89	88.9
		S.D.	6.5	10.7	7.9	7.4	5.6	.....	10.3	6.0	.....	6.2	4.7	6.6	7.1	8.3	7.6
		C.	6.4	12.6	9.6	8.0	5.8	.....	11.1	6.9	.....	7.7	5.7	7.3	7.7	9.3	8.5
Nov. 18	L.	M.	119	96	90	103	94	.....	98	105	.....	95	87	103	105	104	100
		S.D.	13.2	6.8	5.3	9.7	5.8	.....	12.2	7.1	.....	8.7	7.9	5.9	7.3	12.1	8.9
		C.	11.1	7.1	5.9	9.4	6.2	.....	12.5	6.8	.....	9.2	9.1	5.7	7.0	11.6	8.9
	R.	M.	107	83	81	99	104	.....	89	86	.....	85	86	96	98	90	91.4
		S.D.	13.4	6.8	6.2	10.7	10.0	.....	8.3	4.5	.....	5.0	5.7	6.7	8.4	9.3	8.1
		C.	12.5	8.2	7.7	10.8	9.6	.....	9.3	5.2	.....	5.9	6.6	7.0	8.6	10.3	8.7
Dec. 16	L.	M.	.....	86	89	100	103	.....	90	99	.....	92	87	97	104	98	93.7
		S.D.	.....	5.6	11.3	11.4	8.9	.....	9.6	10.5	.....	5.6	5.2	6.4	8.7	3.7	7.5
		C.	.....	6.5	12.7	11.4	8.6	.....	10.7	10.6	.....	6.1	6.0	6.6	8.4	3.8	8.0
	R.	M.	.....	82	82	97	105	.....	90	83	.....	85	82	92	94	85	87.7
		S.D.	.....	5.8	6.9	10.5	12.7	.....	10.5	3.0	.....	5.6	5.2	7.2	11.8	4.7	7.6
		C.	.....	7.1	8.4	10.8	12.1	.....	11.7	3.6	.....	6.6	6.3	7.8	12.6	5.5	8.5
Normal av...	L.	M.	117.5	89.7	88.3	100.3	97.7	.....	95.7	104.0	.....	92.3	88.0	97.7	102.3	98.7	96.3
		S.D.	11.3	7.2	7.9	9.4	7.4	.....	8.6	8.7	.....	7.1	7.3	6.4	7.6	8.7	8.0
		C.	9.6	8.1	9.0	9.4	7.6	.....	9.1	8.4	.....	7.7	8.3	6.6	7.5	8.8	8.3
	R.	M.	104.5	83.3	81.7	96.3	102.0	.....	90.7	85.3	.....	83.7	83.3	92.7	94.7	88.0	89.3
		S.D.	10.0	7.8	7.0	9.5	9.4	.....	9.7	4.5	.....	5.6	5.2	6.8	9.1	7.4	7.8
		C.	9.5	9.3	8.6	9.9	9.2	.....	10.7	5.2	.....	6.7	6.2	7.4	9.6	8.4	8.6
1918. Jan. 14	L.	M.	.....	.....	89	113	.....	110	97	.....	71	96	85	100	101	107	98.5
		S.D.	.....	.....	7.1	10.4	.....	12.0	11.0	.....	5.8	9.1	5.8	6.9	6.3	11.5	8.5
		C.	.....	.....	8.0	9.2	.....	10.9	11.3	.....	8.2	9.5	6.8	6.9	6.2	10.7	8.6
	R.	M.	.....	.....	85	95	.....	85	94	.....	77	86	80	95	92	94	90.1
		S.D.	.....	.....	7.1	6.9	.....	5.9	10.3	.....	5.7	4.0	5.1	6.0	5.8	9.5	6.8
		C.	.....	.....	8.4	7.3	.....	6.9	11.0	.....	7.4	4.7	6.4	6.3	6.3	10.1	7.6
Jan. 20	L.	M.	118	88	91	106	.....	110	99	.....	76	95	84	98	104	108	99.1
		S.D.	11.2	8.8	10.9	10.8	.....	11.9	8.9	.....	6.3	8.4	7.3	7.9	7.5	12.7	9.4
		C.	9.5	10.0	12.0	10.2	.....	10.8	9.0	.....	8.3	8.8	8.7	8.1	7.2	11.8	9.5
	R.	M.	107	83	85	102	.....	93	94	.....	72	83	82	95	92	94	91.7
		S.D.	7.9	7.8	7.1	9.8	.....	8.0	8.3	.....	5.3	8.3	5.5	7.5	7.3	11.3	8.1
		C.	7.4	9.4	8.4	9.6	.....	8.6	8.8	.....	7.4	10.0	6.8	7.9	7.9	12.0	8.8
Low-diet av.	L.	M.	118.0	88.0	90.0	109.5	.....	110.0	98.0	.....	73.5	95.5	84.5	99.0	102.5	107.5	98.8
		S.D.	11.2	8.8	9.0	10.6	.....	12.0	10.0	.....	6.1	8.8	6.6	7.4	6.9	12.1	9.0
		C.	9.5	10.0	10.0	9.7	.....	10.9	10.2	.....	8.3	9.2	7.8	7.5	6.7	11.3	9.1
	R.	M.	107.0	83.0	85.0	98.5	.....	89.0	94.0	.....	74.5	84.5	81.0	95.0	92.0	94.0	90.9
		S.D.	7.9	7.8	7.1	8.4	.....	7.0	9.3	.....	5.5	6.2	5.3	6.8	6.6	10.4	7.5
		C.	7.4	9.4	8.4	8.5	.....	7.8	9.9	.....	7.4	7.4	6.6	7.1	7.1	11.1	8.2

Squad B had two dates with the eye movement measurements, January 14 and 20, under conditions of reduced diet. These results are averaged at the bottom of table 181. The average for L is 98.8 σ, which can be compared with the 96.3 σ of the normal. The average for R is 90.9 σ as against 89.3 σ. The indications are, therefore, that the eye movements were slightly slower during the period of the reduced diet.

Table 180 shows the data of eye-movement speed for Squad A. At their first session, October 28, 3 weeks after the beginning of the reduced diet, the average speed for left movement was 96.6 σ and variability 7.3 per cent. The average speed for right movement was 93.1 σ with variability 6.6 per cent. Individual subjects ranged, left, from 84 to 112 σ for *Gul* and *Gar*, and for right from 76 to 114 σ for *Kon* and *Spe*.[1] In the variability for left movements, the men ranged from 3.3 to 10.4 for *Vea* and *Tom*. For right movements they ranged from 4.7 to 11.0, *Can* and *Gul* and *Mon*.

The individuals of Squad A have averages for the dates October 28, November 25, December 9, January 13, and January 27.[2] The averages for all of these dates are shown at the bottom of table 180. The total average for the 10 men is for left movements, 101.6 σ, for right, 93.3 σ. The variability is 9.1 and 8.3 per cent, respectively, for left and right. Thus all of the averages for eye movements shown by members of Squad A fall within the range found for the normal series of 1917.

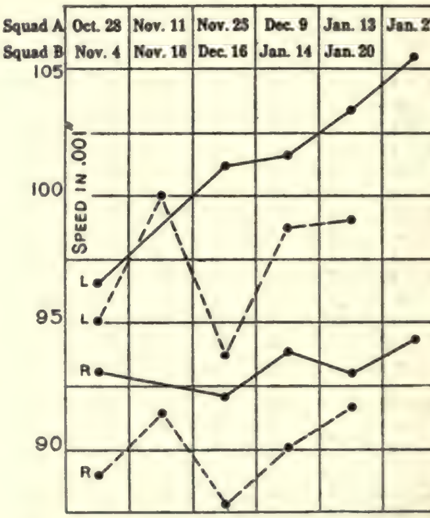

FIG. 117.—Speed of the eye movements.

L and *R* designate movements to the left and to the right. Solid lines represent Squad A, broken lines Squad B.

The influence of the low-diet condition upon this muscle coordination process may be judged better from the data presented in diagrammatic form in figures 117 and 118. In figure 117 the solid lines represent, as in other curves, the data of Squad A. The two curves in each case are designated L and R, for left and right. The speed of the movements left shows a definite and regular lengthening with the

[1] The record of 114 σ for *Spe* is associated with an error in the procedure in that the left eye was not covered.

[2] The measurement was also used on November 11, but owing to a difficulty with the apparatus the records were nearly all failures.

progress of the experiment. The time requirement gradually increased from about 97 to 106 σ, a lengthening of 9.3 per cent. It is true that not all of the subjects of Squad A demonstrate this same change. For example, *Can* has values for the left movements for the different dates as follows: 94, 88, 94, 87, and 87 σ. On the other hand, we may point out *Gar*, whose values for left are 112, 114, 108, 120 and 131 σ. With the majority of subjects the length of time tends to increase from October 28 until January 27. The eye movements to the right (see solid line for *R* in fig. 117) show almost no progressive change during the low-diet period. This difference between the right movements and the left movements is a surprising fact, but it absolutely agrees with results previously found in this Laboratory.[1] It was found n the investigation with small amounts of alcohol that with the eye movements the alcohol effect was predominantly upon movements to the left in the ratio of 10 to 4.

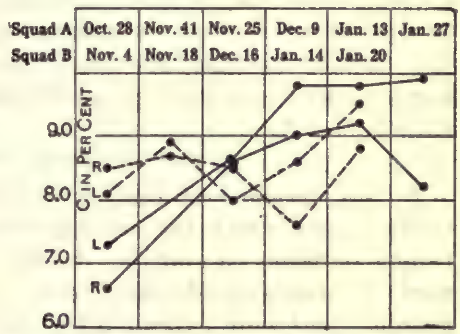

FIG. 118.—Variability in the speed of the eye movements.

L and *R* designate movements to the left and to the right. Solid lines represent Squad A, broken lines Squad B.

Squad B (see the broken line in fig. 117) demonstrates a wide range of variation between their three normals, November 4, November 18, and December 16. Some uncontrolled influence was operating on November 18, but definite information is lacking. It is very apparent that it influenced the movements to the left more strongly than it did those to the right. The average results for the low-diet dates January 14 and 20 show slower speed than the two normal dates, November 4 and December 16. This is particularly true with the movements to the left, thus agreeing with the results for Squad A. Including in the average the aberrant values of November 18 with these normals for November 4 and December 16, it is still true, as shown in table 181, that the average for the low diet shows slower speed than for normal conditions. The results of the two squads therefore substantiate each other in the direction of the low-diet effect on this neuro-muscular process of eye movements. It appears with both groups of men that the muscle coordination of moving the right eye from a point at the right of the field of vision to a point at the left is more delicate and easily disturbed than the complementary coordination for movements of the same eye from a point at the left through 40° to the right.

[1]Dodge and Benedict, Carnegie Inst. Wash. Pub. No. 232, 1915, p. 163, table 26.

The average variability of the two squads for right and left movement is presented in figure 118. Squad A appears to show a gradual increase in the variability, which is high for December 9, January 13, and January 27, except that on the latter date the variability for *R* was decreased. In the case of Squad B the variability is larger on November 18 than for the other two normal dates. It also rises at the point of January 20 during the low-diet experiment. Squad B shows no considerable increase in the variability at their first low-diet date. This would appear to agree, also, with Squad A. Since the first date for Squad A, October 28, was during the early part of the low-diet period and showed a variability of nearly 7 per cent, we judge this to be about as small as could reasonably be expected.

Associated with the prolonged reduced diet the eye movements show a slower speed in the case of Squad A amounting in the extreme to approximately 5 per cent for averages of movements right and left. With this there is also an increase in the variability. The results for this measurement found on Squad B confirm the direction of those observed with Squad A.

(15) SPEED OF THE FINGER MOVEMENTS.

In this muscle coordination test the number of complete oscillations of the finger which the average individual can perform in 10 seconds ranges between 55 and 75. In the normal series of 1917 finger-movement records were obtained on 61 of the men, the records were photographic, and were extended for only 8 seconds. The average for the group of 61 normal men in the 1917 series on whom such records were taken was 52.1 complete oscillations in 8 seconds. The records made in the evening for Squads A and B are given in tables 182 and 183. The average performance on the normal date (September 29) for Squad A was 68.7 oscillations; the average for the first experiment with Squad B was 66.0 oscillations. The foregoing values are for records 10 seconds long. If we count only the first 8 seconds so as to make them comparable with the normal series of 1917, the initial normal results are 55.7 and 53.7 oscillations for A and B, respectively. Thus the two groups of men agree fairly well with each other and with the larger normal group. With Squad A the individual normal averages range from 52.3 oscillations for *Tom* to 84.6 oscillations for *Gul*. This last figure is unusually high. *Gul* has previously been noted as a rather short, extremely intense individual. With Squad B the range for the first experiment for the individual subjects is smaller, being from 58.2 for *How* to 72.5 for *Wil*. The members of A show individual averages exclusive of the first (normal) experiment, which range from 56.5 oscillations for *Moy* to 77.5 oscillations for *Gar*. The average for the 10 subjects for the nine evening experiments is 65.1 oscillations. Squad B show individual averages for their five normal evening experiments which range from 58.6 (*How*) to 75.2 (*Van*), with a total average of

65.6 oscillations. For the three evening experiments during the reduced diet period the average is 62.7 oscillations, a reduction from the normal average of 2.9 oscillations, which corresponds to 4.4 per cent. The difference between the normal of Squad A and the average for their nine low-diet periods is 3.6 oscillations, amounting to 5.2 per cent of the normal.

TABLE 182.—*Squad A—Number of finger movements performed in 10 seconds at evening sessions.*

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.
1917.														
Sept. 29	75.6	60.5	56.5	79.3	84.6	55.4	63.3	64.5	76.8	73.1	52.3	75.1	60.9	68.7
Oct. 13	71.7	59.1	....	76.8	73.5	49.7	58.8	62.6	78.1	69.4	53.8	71.7	57.6	65.6
Oct. 27	71.1	59.0	62.4	80.6	76.8	50.1	60.9	61.2	80.7	74.5	57.3	67.8	....	66.6
Nov. 10	69.8	60.9	57.1	75.9	74.1	52.4	57.1	61.0	72.5	72.4	53.5	65.1	....	64.2
Nov. 24	72.8	60.2	54.8	80.8	67.8	57.9	57.6	58.4	70.2	67.5	55.5	61.8	....	64.3
Dec. 8	72.4	59.4	56.2	73.7	65.4	59.8	54.7	59.7	68.2	67.4	57.2	63.3	....	63.4
Dec. 19	71.9	61.8	57.7	75.2	64.4	60.3	61.4	58.0	69.9	....	59.3	67.1	....	64.9
1918.														
Jan. 12	71.7	59.2	62.2	76.6	75.5	58.4	51.1	60.1	75.7	....	59.7	66.4	....	65.4
Jan. 26	70.8	62.0	59.7	75.2	67.5	60.0	50.7	59.1	68.8	....	57.9	63.2	....	63.5
Feb. 2	69.6	62.9	55.1	82.4	78.4	61.6	55.8	64.4	74.0	....	60.7	66.5	....	67.6
Low-diet average	71.3	60.5	58.2	77.5	71.5	56.7	56.5	60.5	73.1	70.2	57.2	65.9	....	65.1

TABLE 183.—*Squad B—Number of finger movements performed in 10 seconds at evening sessions.*

Date.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917.															
Oct. 6	65.1	63.3	58.2	67.7	....	....	60.9	65.3	....	68.1	70.7	67.3	....	72.5	66.0
Nov. 3	61.1	60.1	58.7	72.0	68.0	....	57.2	59.8	....	66.7	65.6	65.2	71.9	73.8	65.2
Nov. 17	60.0	58.7	58.3	71.0	76.3	....	60.8	62.5	....	69.9	68.8	61.9	76.0	70.1	65.6
Dec. 15	....	58.2	57.5	64.3	78.9	....	59.3	66.5	....	69.1	65.8	62.8	75.5	70.2	64.7
1918.															
Jan. 5	62.3	59.1	60.4	67.7	72.5	60.2	....	....	65.6	65.9	67.8	61.4	77.2	76.3	66.5
Normal av.	62.1	59.9	58.6	68.5	73.9	60.2	59.5	63.5	65.6	67.8	67.7	63.7	75.2	72.6	65.6
Jan. 13	58.6	58.9	58.0	64.5	....	67.1	55.9	....	70.6	70.0	68.7	60.2	75.1	71.7	64.2
Jan. 19	62.1	55.6	55.7	63.1	....	63.4	55.5	....	69.9	64.4	66.6	60.4	74.8	65.4	62.4
Jan. 27	54.5	60.4	51.5	65.6	....	58.1	55.6	....	73.4	68.1	63.4	56.0	72.8	66.4	61.4
Low-diet av.	58.4	58.3	55.1	64.4	....	62.9	55.7	....	71.3	67.5	66.2	58.9	74.2	67.8	62.7

The course of the changes in these finger-movement records is made clear by figure 119. There are fluctuations, but it is very evident that Squad A on the average for the 10 men did better in their normal experiment than at any other time. The total number of finger movements in 10 seconds rather regularly decreased to December 8. There was some recovery on December 19 and January 12, a conspicuous

fall on January 26 with an evident spurt at the last session on February 2. Squad B did not show their highest point until January 5. Previous to this time the fluctuations tended, in general, toward a slight decrease, amounting, between October 6 and December 15, to a little more than one oscillation. The decrease during the normal period

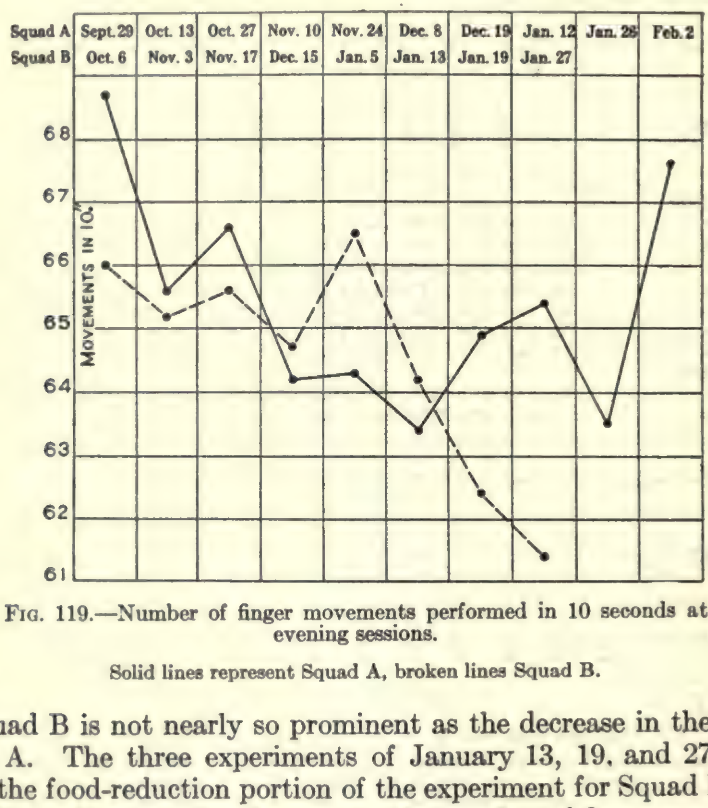

FIG. 119.—Number of finger movements performed in 10 seconds at evening sessions.

Solid lines represent Squad A, broken lines Squad B.

for Squad B is not nearly so prominent as the decrease in the case of Squad A. The three experiments of January 13, 19, and 27, which fall in the food-reduction portion of the experiment for Squad B, show a definite and progressive decrease in the number of finger movements

TABLE 184.—*Squad A—Number of finger movements performed in 10 seconds at morning sessions.*

Date.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av.
1917.													
Oct. 28	74.3	64.0	61.7	79.5	79.9	54.4	61.3	63.6	74.0	79.8	56.1	70.7	67.8
Nov. 11	74.6	63.4	66.6	74.9	76.9	55.1	56.1	64.0	73.9	64.4	56.8	68.8	66.5
Nov. 25	70.8	61.0	61.5	82.5	65.5	58.0	58.7	61.0	71.2	70.9	57.6	69.5	65.6
Dec. 9	70.2	61.2	58.5	75.6	68.5	61.2	55.7	65.1	70.1	66.6	56.6	69.5	65.4
1918.													
Jan. 13	67.0	63.7	67.7	77.2	70.9	60.8	57.7	63.4	75.3	....	61.1	71.8	66.9
Jan. 27	62.1	63.3	58.7	73.1	77.4	63.5	56.6	62.5	71.1	....	58.8	68.3	65.7
Low-diet average	69.8	62.8	62.5	77.1	73.2	58.8	57.7	63.3	72.6	70.4	57.8	69.8	66.3

performed in 10 seconds, and all are below the previous records for this squad. The records for the last two dates are considerably lower than any of those found for Squad A.

TABLE 185.—*Squad B—Number of finger movements performed in 10 seconds at morning sessions.*

Date.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917.															
Nov. 4........	64.5	56.6	56.4	69.5	72.3	....	60.9	63.4	....	71.2	71.8	70.1	76.1	71.8	66.9
Nov. 18........	58.0	62.7	57.9	72.5	77.8	....	61.0	62.0	....	69.2	69.1	63.2	77.4	72.1	66.3
Dec. 16........	....	55.2	57.9	69.8	73.3	....	58.4	62.3	....	68.1	70.5	64.5	75.0	73.8	66.0
Normal av...	61.3	58.2	57.4	70.6	74.5	....	60.1	62.6	....	69.5	70.5	65.9	76.2	72.6	66.4
1918.															
Jan. 14........	62.9	59.5	59.3	68.5	....	57.6	61.3	....	76.7	66.0	69.9	64.3	75.3	72.3	65.9
Jan. 20........	57.7	56.9	54.6	67.9	....	58.6	55.6	....	70.5	67.1	63.5	61.3	76.7	57.7	61.9
Low-diet av..	60.3	58.2	57.0	68.2	....	58.1	58.5	....	73.6	66.6	66.7	62.8	76.0	65.0	63.9

Before drawing final conclusions regarding the relation of the low diet to this muscle-coordination test, we must inspect the data taken in the morning trials. These data are presented in tables 184 and 185. The average performance for Squad A the first time these morning measurements were made was 67.8 oscillations. This experiment was made on the morning following the third evening experiment, for the morning finger-movement tests were not begun until after Squad A had been several weeks on low diet. Hence this figure can not be compared directly with the normal for the evening of September 29, but should be compared with the value for the evening of October 27, which is 66.6 oscillations. It is therefore 1.2 oscillations higher than the evening record. The morning record for November 11, which

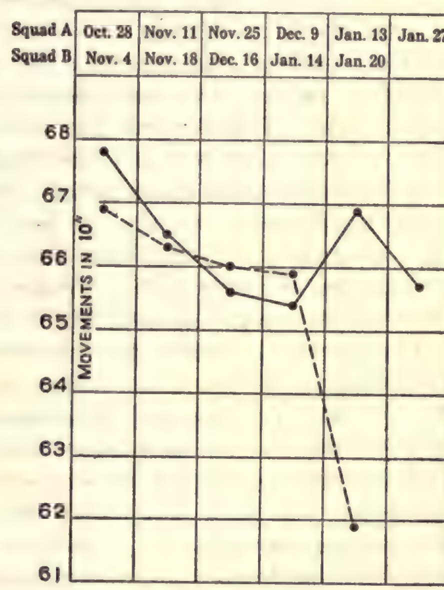

FIG. 120.—Number of finger movements performed in 10 seconds at morning sessions.

Solid lines represent Squad A, broken lines Squad B.

is 66.5 oscillations, should likewise be compared with the evening record of November 10 of 64.2 oscillations, the difference in favor

of the morning record being 2.3 oscillations. This difference of approximately two oscillations applies throughout the records, the morning records always being the higher for Squad A. With Squad B, if we compare the evening of November 3 with the morning of November 4, the scores are, respectively, 65.2 and 66.9 oscillations, a difference of 1.7 oscillations in favor of the morning. Throughout the measurements for Squad B, the morning tests give a higher score by approximately 1.5 oscillations. The two series of finger movements are thus in entire contrast to the results found in the strength of grip test in which the evening performance was the better. (See p. 585.)

The individual averages in tables 184 and 185 call for no special comment. The group results are plotted in figure 120. Squad A shows a continual decrease from October 28 to December 9. In the evening records, December 8 also showed the poorest record, although the curves were fairly regular up to that time. It may be assumed that the score for October 28 is a little high if the curve for the evening records is taken as a basis, for on the previous evening, October 27, the score was higher than it had been previously by about 1 oscillation. No finger movements were taken on the morning of December 20 on account of the electrocardiograms. There is a high point in the curve for January 13 which corresponds well with that found for the evening of January 12; following this there is a decline on January 27 which is also found on January 26. No records could be taken on the last morning, as the time was given up almost entirely to the walking experiment. The records for Squad B, also shown in figure 120, demonstrate a gradual decline from November 4 to January 14, the first food-reduction experiment. On January 20, the second experiment which came within the food-reduction period, there is a precipitous drop of 4 oscillations from the preceding record of 65.9, which is a decline of 6 per cent. Finger movements could not be taken on the final morning, January 26, on account of the walking experiment.

The finger movement records were counted in blocks of 2 seconds.[1] For example, the records of *Gul* in the evening experiment of September 29 for the five 2-second intervals,[2] were 18.6, 16.7, 16.7, 16.4 and 16.2 oscillations in each succeeding 2-second period, with a total of 84.6 oscillations for the 10 seconds; (see table 182). Comparison of the results in such short and successive intervals may be counted on to show the influence of fatigue which, however, in the 10-second test, does not develop to an unpleasant degree. The records, tabulated as illustrated for *Gul* on the one date, are wonderfully uniform in the amount of decrease from one 2-second period to the next; in conse-

[1]The tables for finger movements given by Miles, Carnegie Inst. Wash. Pub. No. 266, 1918, p. 86, are in this form.

[2]These 2-second intervals were accurately marked on the record by the timed jump spark from the recording point (see p. 187).

quence it did not seem justifiable to increase the size of tables 182 to 185 fivefold by printing these 2-second data.

The averages are shown diagrammatically in figure 121. To avoid complicating the figure, the results for evening and morning records are grouped separately. The columns or ordinates from left to right are headed I 2 seconds, II 2 seconds, etc. Each curve has a designation. The regularity of decline in the seven curves tells its own story without further discussion. The curves (*A* and *B*) for the evening normals are not so straight as are those for the low-diet results (*A′* and B′). The fall from one 2 seconds to the next 2 seconds is uniformly 0.3 or 0.4 of a complete finger movement. Had we only the evening data of Squad B, it might be thought that early fatigue developed a little more slowly under conditions of food reduction and at the lower level of performance which then obtains. The results with Squad A and the morning results with B do not agree; there is thus no consistent indication of a change in fatigue development or latency with the food reduction. The difference in number of finger movements performed under normal and low-diet conditions is substantially the same whether one takes 2, 4, 6, 8, or 10 second records. It is apparently a difference in level rather than one of readiness or fatigue of the process.

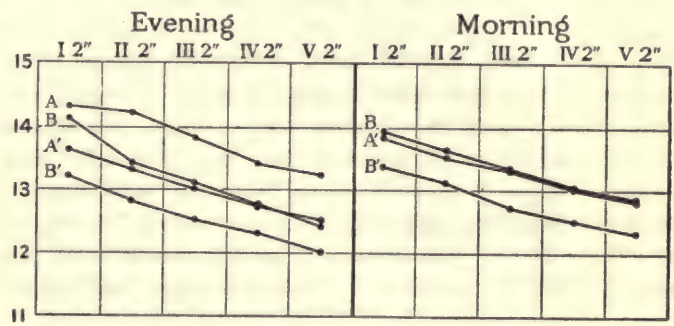

FIG. 121.—Number of finger movements performed in successive 2-second intervals.

The scale at the left shows complete oscillations. Results for evening and morning records are diagrammed separately. *A*, Squad A normal; *B*, Squad B normal; *A′*, Squad A on low diet; *B′*, Squad B on low diet.

It is clear that there was a decrease in the efficiency of the motor coordination of finger movements which quite evidently resulted from the food reduction. The decrease, with fluctuation, is shown in the case of Squad A in both the evening and morning records and was very prominent with Squad B during the three weeks' period of food reduction. Judging from the evening records of Squad A, the decrease in the finger movements incident to the food reduction was fully 5 per cent.[1] Squad A during the greater number of experiments were below B, even though they were normally capable of a faster rate than B, as was shown on September 29.

[1]Four of the evening experiments during food reduction show a decrement as great or greater than 6.4 per cent.

(16) EFFICIENCY IN TRAVERSING A RIGHT-ANGLE MAZE.

Two groups of individuals may conceivably show the same initial results in a test or measurement and later, upon repetition of the same task, may demonstrate different degrees of learning ability and rate of improvement. The ability to learn and the conditions which favor or oppose it are of great significance. The maze test was used in this study of the effect of food reduction on men to throw light on this question. It is evident that in repeatedly solving this problem according to directions (see p. 189) the subjects would naturally require shorter and shorter time intervals.

This test, with the same directions and conditions, was used in the normal series of 1917. A group of 67 normal college men, most of them upper classmen or recent college graduates, performed the task three times in succession. The men were carefully observed, and the time from beginning to successful completion of each trial accurately recorded. The classified results for the first two trials are given in table 186. At the initial trial one man did the task in 58 seconds; 23 of the group, that is 34 per cent, completed it in from 101 to 200 seconds; 5 required 600 seconds or more; 2 men failed entirely, giving it up after 18 and 33 minutes, respectively. In the second trial, which was begun about 15 seconds after the first trial was completed, 8 of the men did it in 50 seconds or less, and only one of the 65[1] who completed it required more than 600 seconds. The range in the first trial was from 58 to 1,150 seconds; for the second trial, it was from 35 to 637 seconds; the latter value is from the same individual whose first trial

TABLE 186.—*Distribution of men in normal series of 1917 according to number of seconds required to complete the maze test.*

Ranges.	50 or less.	51 to 75.	76 to 100.	101 to 200.	201 to 300.	301 to 400.	401 to 500.	501 to 600.	601 or more.
First trial......	0	1	11	23	12	7	3	3	5
Second trial....	8	15	17	18	3	2	1	0	1

required the 1,150 seconds. The man who did best in the first trial had values for the three tests as follows: 58, 42, and 76 seconds. In the third trial he became careless and overconfident and lost speed. The individual who showed the best record in the second trial had values for the three trials as follows: 87, 35 and 19 seconds. Some of the other subjects showed very rapid performance with consistent improvement; for example, No. 1, with records of 76, 50, and 45

[1]There was no second trial for the men who are noted as failing in the first. Of course literally these men tried many times, *i. e.*, they made many fresh starts, but always got hopelessly lost through their failure to follow the directions carefully. The third trial followed the second trial after a short intermission, but for one reason or another six of the aviation candidates did not do the task a third time and these data have not been tabulated in table 186. The men in the low-diet research made only one trial to completion on each evening.

seconds; No. 45 with 85, 41, and 33 seconds; and No. 63, whose time was 77, 40, and 31 seconds. These records are of course exceptional. The score of 19 in the third trial is the shortest time in which any one has so far completed the task. The averages for the three trials in order for the whole group are: 264, 119, and 90 seconds.

On each evening the subjects of the low-diet research traced completely through the maze but *once* and, with the exception of *Mon,* had no other practice. The first trial of our subjects is therefore comparable with that of the aviators.

TABLE 187.—*Squad A—Efficiency in performing the maze test.*
[Time in seconds.]

Date.	Statement of score.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.[1]	Moy.	Pea.[2]	Pec.	Spe.	Tom.	Vea.	Fre.	Av.[3]
1917.															
Sept. 29...	Time	555	268	192	303	177	1800+	163	322	249	261	106	282	104	270
	Starts	([4])	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oct. 13...	Time	83	316	.....	660	206	432	124	93	211	139	106	59	61	206
	Starts	1	1	.....	2	3	3	2	1	2	2	1	1	1	1.6
Oct. 27...	Time	96	211	154	1110	87	1000+	58	75	153	173	94	293	.....	242
	Starts	2	2	2	3	1	7	1	1	1	3	1	2	.....	1.6
Nov. 10...	Time	64	395	66	179	190	626+	37	88	169	98	65	89	.....	142
	Starts	1	2	1	1	2	5	1	1	2	2	1	1	.....	1.3
Nov. 24...	Time	61	174	121	104	60	667+	29	50	121	76	38	43	.....	75
	Starts	2	1	3	1	1	6	1	1	1	1	1	1	.....	1.1
Dec. 8...	Time	75	157	64	177	59	628+	26	34	106	68	97	237	.....	107
	Starts	2	1	1	2	1	7	1	1	1	1	2	3	.....	1.6
Dec. 19...	Time	66	141	74	77	44	525+	27	37	86	.....	113	25	.....	68
	Starts	2	1	2	1	1	3	1	1	1	.....	2	1	.....	1.2
1918.															
Jan. 12...	Time	30	136	41	73	57	640+	26	51	93	.....	37	56	.....	62
	Starts	1	1	2	1	1	5	1	1	1	.....	1	1	.....	1.0
Jan. 26...	Time	61	106	29	198	38	400+	26	39	89	.....	38	26	.....	69
	Starts	2	1	1	2	1	3	1	1	1	.....	1	1	.....	1.2
Feb. 2...	Time	53	267	26	56	29	220+	23	65	72	.....	29	30	.....	69
	Starts	1	3	1	1	1	3	1	2	1	.....	1	1	.....	1.3
Low-diet av......	Time	65.4	211.4	71.9	292.7	85.6	......	41.8	59.1	122.2	110.8	68.6	95.3	61	115.6
	Starts	1.6	1.4	1.6	1.6	1.3	......	1.1	1.1	1.2	1.8	1.2	1.3	.....	1.4

[1] *Mon* apparently developed a complex against this test; he never succeeded in completing the test at the appointed time. He did do it once or twice out of hours. His results are not included in the average.
[2] *Pea* was left-handed and the left hand was used in the tracing-box with right hand on top of box.
[3] The records of *Mon, Kon, Spe,* and *Fre* are not included in this average.
[4] No record kept of number of starts on first night.

In tables 187 and 188 the data are given for Squads A and B. Nine men of Squad A (omitting *Kon, Mon, Spe,* and *Fre,* for reasons given in the footnotes to table 187 and elsewhere in the text) show an average in their first performance (September 29) of 270 seconds. This compares remarkably well with the average of 264 seconds for the normal series of 1917. The range aside from *Mon,* who failed, is from 104 to 555 seconds. None of the men performed the test as quickly as

did 12 of the aviators at their first attempt. (See table 186.) Squad B, table 188, in their first trial had approximately the same range as Squad A, that is, from 128 to 526 seconds. One man, *How*, after 1,410 seconds, was unable to complete the test and there was no time for further trial. The average for the initial test of Squad B on October 6, excluding *How*, who did not succeed, and *Mac*,[1] is 208 seconds, that is, somewhat lower than what would normally be expected.

TABLE 188.—*Squad B—Efficiency in performing the maze test.*
[Time in seconds.]

Date.	Statement of score.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.[1]
1917. Oct. 6	Time	204	134	[2]1410+	450	.....	.....	128	252	.....	165	131	180	526	157	208
	Starts	([3])	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Nov. 3	Time	272	99	770	191	976	.....	359	753	.....	211	143	645	130	269	309
	Starts	2	1	7	2	10	.....	3	4	.....	2	1	4	1	3	2.6
Nov. 17	Time	200	244	248	288	380	.....	106	500	.....	66	81	207	189	264	189
	Starts	1	2	2	3	3	.....	1	3	.....	1	1	1	1	3	1.6
Dec. 15	Time	.....	182	397	141	488	.....	197	280	.....	46	71	92	185	68	153
	Starts	.....	1	5	2	5	.....	2	1	.....	1	1	1	1	1	1.7
Jan. 5	Time	87	51	119	49	220	.....	.....	.....	590	60	116	93	88	61	80
	Starts	1	1	2	1	3	.....	.....	.....	4	1	2	1	1	1	1.2
Normal av...	Time	191	142	384	224	516	.....	198	446	594	110	108	243	224	164	188
	Starts	1.3	1.3	4.0	2.0	5.3	.....	2.0	2.7	4	1.3	1.3	1.8	1	2	1.8
Jan. 13	Time	103	42	43	217	.....	374	70	.....	164	77	56	66	69	51	79
	Starts	1	1	1	3	.....	3	1	.....	1	1	1	1	1	1	1.2
Jan. 19	Time	71	41	61	44	.....	75	37	.....	200	37	50	58	281	47	73
	Starts	1	1	1	1	.....	1	1	.....	1	1	1	1	4	1	1.3
Jan. 27	Time	61	39	51	41	.....	46	40	.....	163	29	50	50	105	36	50
	Starts	1	1	1	1	.....	1	1	.....	1	1	1	1	2	1	1.1
Low-diet av.	Time	78	41	52	101	.....	165	49	.....	176	48	52	58	152	45	67
	Starts	1	1	1	1.7	.....	1.7	1	.....	1	1	1	1	2.3	1	1.2

[1] These averages do not include *McM*, *Kim*, *Mac*, and *Sch*.
[2] Not in the average.
[3] Number of starts not recorded on first day.

It is unnecessary to discuss the individual values. Aside from some irregularities nearly all the subjects show a rather consistent reduction in time required for the task from experiment to experiment. In the nature of the case, it could not be expected that the normal average and the low-diet average of Squad B would be directly comparable. The average values for both squads are plotted in figure 122. It is noteworthy that the two curves are nearly at the same level and follow the same general course; they may reasonably be regarded as normal practice curves. Squad B was somewhat handicapped by the longer interval between their first and second experiments, that is,

[1] The latter is excluded because his records are not complete for the food reduction period.

from October 6 to November 3, and there is a marked decline on the latter date. Inspection of table 188 will show that 7 of the men increased the time for performing the task. They seem to have approached the problem in an overconfident attitude, and not to have paid careful attention to the directions. Five of these men who required a longer time at the second trial became confused; these subjects had to make three or four beginnings before they completed the task.[1] Another cause for the depression in the curve of Squad B on November 3 is that on this date *How* was included, but he was not included in the average for October 6 as he failed to complete the task. His score for November 3 is largest of all, being 770 seconds. Beyond this point,

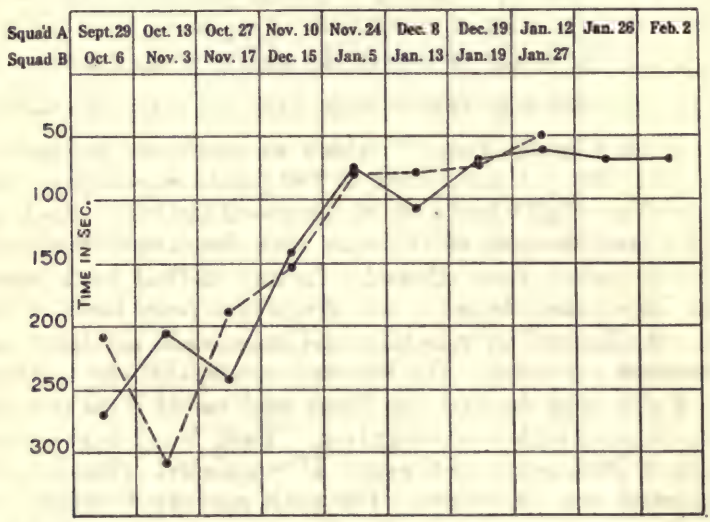

FIG. 122.—Average time required to complete the maze-tracing task.
Solid lines represent Squad A, broken lines Squad B.

Squad B continued to improve and reached a level on January 5, from which they improved very slowly on the three food-reduction dates.

The curve for Squad A is depressed on October 27. This is not shown by the individual performance of all the group, but appears to be due largely to the poor and irregular performance of *Gar* and *Vea;* the former became confused twice and was obliged to begin again, with the result that the time required (1,110 seconds) is the longest in table 187 for the 9 men whose records are averaged. There is also a depression in the curve on December 8. This was also due to the irregular work of *Vea* and *Gar*, and to some extent of *Tom*. The averages for the last

[1]No record was kept of the number of beginnings required on the first evening. This record for later experiments is included in the table, as it illuminates the time record, indicating in the case of a long time whether they moved very slowly and carefully or carelessly.

four dates of Squad A show an even level of about 70 seconds, approximately the same as that for Squad B and somewhat less than the average for the third trial of the normal series of 1917, *i. e.*, 90 seconds.[1] It is of course impossible to predict what the result with the group of 67 men would have been had they taken the test the same number of times in experiments separated by the same time intervals as those for Squads A and B, but considering the fact that the two squads show results which are comparable and which in the initial trials compare favorably with those for the larger group of 1917, and furthermore, considering that the two squads show practice of about the same rate and finally reach the same level, it seems reasonable to conclude that in this task of learning to follow a certain pattern and to coordinate correctly a certain series of movements in so doing, the food reduction did not definitely hinder or reduce the ability to improve.

(17) EFFICIENCY IN PERFORMING CERTAIN CLERICAL TASKS.

The "Wells Clerical Test C" which we employed is divided into 6 parts (see fig. 56). A total score of 100 points was allowed for a perfect completion of all 6 tasks which composed the test. Each task was assigned a possible score of 18 points with the exception of number 5, to which 10 points were allowed. In any clerical work accuracy is of prime importance, hence it was given first place here. The scale of demerits adopted for mistakes and erasures is arbitrary and may be considered excessive. We followed essentially the methods used by Dr. Wells, who devised the blank and called it to our attention in connection with this investigation. Task No. 1 was composed of 20 constant increment additions. If completed without error, the score allowed was 18 points. For each mistake 6 points were deducted; three or more errors therefore meant a score of 0.[2] Task No. 2 consisted of two problems in long division; the result was always a whole number. For correct results, 9 points were allowed with each problem; an incorrect result received no credit. In Task No. 3 a group of 10 four or five-figure numbers had to be arranged in

[1]In the normal series of 1917, there were only 61 records for time in the third trial. The cases omitted were those in which an abnormally long time had been required for the first and second trials. The subjects were somewhat discouraged and did not care to proceed with another trial, and furthermore an abnormally large amount of time had already been consumed with the measurement. In the normal tests of 1917 the maze was placed last with a part of the men, so that if the subject became discouraged in this task this feeling would not affect prominently results with subsequent measurements. The change to the last measurement in the program for the normal series of 1917 was first made with subject No. 35. Previous to that it had been given before the memory-saving, eye-reaction, and eye-movement tests. In the present research it could not well be the last test with each subject. It was unlikely, however, that this was of any particular importance, except in the case of *Mon*, who repeatedly failed to complete it perhaps because of an attitude formed at the first time, September 29, when he spent so long on it and still failed. This repeated failure in the maze worried the subject. He more than once remarked that everything was all right except the maze.

[2]A score of less than 0 was never given in any of the 6 tests of which the blank was composed, *i. e.*, if a subject made more than 3 errors in one task, nothing on this account was deducted from the score in other parts of the test.

order of size. Scores were allowed as follows: All correct, 18 points; one erasure, 15 points; two or more erasures, 12 points; two transposed, 6 points; more than two transposed or uncorrected, 0. Task No. 4, 10 names were to be numbered in alphabetical order. The scores allowed were: All correct, 18; 1 erasure, 15; 2 or more erasures, 12; 2 names transposed, 6; more than 2 transposed, 0. Task No. 5 was the copying of 6 nine-place numbers. If all were copied correctly the score was 10; with 1 digit wrong or 2 transposed, 5; 2 digits wrong or 3 transposed, 0. In task No. 6, in which the subject was required to describe the location of a certain item and in the second part to locate certain items according to direction, a perfect record was scored 18 points; 1 mistake, 12 points; 2 mistakes, 6 points; 3 or more mistakes, 0 credit.

TABLE 189.—*Squad A—Accuracy in performing the clerical tasks.*

[Values given for total time in seconds, total number of points made, and number of points per min.]

Date.	Statement of score.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Fre.	Av.
1917.															
Sept. 29	Time.....	490	876	595	762	546	721	742	604	1027	645	459	628	428	686
	Points....	100	91	52	73	73	82	55	56	61	73	64	91	82	74.6
	P. per min.	12.3	6.2	5.3	5.8	8.0	6.8	4.5	5.6	3.6	6.8	8.4	8.7	11.5	6.99
Oct. 13	Time.....	522	813	.....	776	689	476	490	403	967	683	388	554	271	608
	Points....	88	67	.....	88	88	94	76	64	85	64	82	76	97	80.8
	P. per min.	10.1	4.9	.....	6.8	7.7	11.9	9.3	9.5	5.3	5.6	12.7	8.2	21.5	8.64
Oct. 27	Time.....	422	828	548	688	694	1355	685	407	755	570	437	482	.....	675
	Points....	85	59	79	91	67	51	76	86	73	76	64	79	.....	73.1
	P. per min.	12.1	4.3	8.7	7.9	5.8	2.3	6.7	12.6	5.8	8.0	8.8	9.8	.....	7.61
Nov. 10	Time.....	435	525	737	552	400	577	476	424	760	421	395	404	.....	495
	Points....	79	82	73	94	88	61	88	79	64	74	97	82	.....	81.4
	P. per min.	10.9	9.4	6.0	10.2	13.2	6.3	11.1	11.2	5.1	10.5	14.7	12.2	.....	10.4
Nov. 24	Time.....	407	732	682	517	363	528	449	417	734	653	412	521	.....	508
	Points....	91	82	82	100	97	88	88	94	82	80	94	76	.....	89.2
	P. per min.	13.4	6.7	7.2	11.6	16.0	10.0	11.8	13.5	6.7	7.4	13.7	8.8	.....	11.2
Dec. 8	Time.....	369	422	622	424	357	509	427	369	583	693	313	355	.....	413
	Points....	100	76	64	100	97	76	91	97	79	67	82	100	.....	89.8
	P. per min.	16.3	10.8	6.2	14.2	16.3	9.0	12.8	15.8	8.1	5.8	15.7	16.9	.....	13.6
Dec. 19	Time.....	455	525	532	529	361	650	426	436	651	.....	355	468	.....	486
	Points....	91	88	64	94	82	79	76	77	76	.....	91	100	.....	85.4
	P. per min.	12.0	10.1	7.2	10.7	13.6	7.3	10.7	10.6	7.0	.....	15.4	12.8	.....	11.0
1918.															
Jan. 12	Time.....	414	547	578	683	333	430	416	352	669	.....	383	421	.....	465
	Points....	88	70	64	94	81	97	100	94	82	.....	94	91	.....	89.1
	P. per min.	12.7	7.7	6.6	8.3	14.6	13.5	14.4	16.0	7.4	.....	14.7	13.0	.....	12.2
Jan. 26	Time.....	356	434	529	455	379	485	388	381	706	.....	481	347	.....	441
	Points....	94	88	55	91	76	79	92	88	58	.....	94	94	.....	85.4
	P. per min.	15.8	12.2	6.2	12.0	12.0	9.8	14.2	13.9	4.9	.....	11.7	16.2	.....	12.3
Feb. 2	Time.....	377	458	481	424	364	412	370	269	698	.....	336	360	.....	407
	Points....	100	100	91	100	58	97	100	76	73	.....	64	91	.....	85.9
	P. per min.	15.9	13.1	11.4	14.2	9.6	14.1	16.2	17.0	6.3	.....	11.4	15.2	.....	13.3
Low-diet av.	Time.....	417	587	589	561	438	602	459	384	725	604	389	435	.....	500
	Points....	91	79	71	95	82	80	87	84	75	72	85	88	.....	83.2
	P. per min.	13.2	8.8	7.4	10.7	12.1	9.4	11.9	13.3	6.3	7.5	13.2	12.6	.....	11.1

The result for the clerical tests with Squads A and B are given in tables 189 and 190. A subject's performance in filling out the blank is represented in the table by three values: (1), the total time required to fill out the blank to his own satisfaction; (2), the number of points which he received without reference to the time expended in performing the task; (3), the average number of points per minute. For illustration: On September 29 (see table 189) the total

TABLE 190.—*Squad B—Accuracy in performing the clerical tasks.*

[Values given for total time in seconds, total number of points made, and number of points per min.]

Date.	Statement of score.	Fis.	Har.	How.	Ham.	McM.	Kim.	Lon.	Mac.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
1917. Oct. 6	Time.....	892	724	(1)	823	......	......	963	1014	......	1163	873	666	(1)	785	860
	Points....	88	85	82	94	......	......	97	37	......	81	64	94	82	79	84.6
	P. per min.	5.9	7.0	(1)	6.9	......	......	6.0	2.2	......	4.2	4.4	8.5	(1)	6.0	6.11
Nov. 3	Time.....	820	716	607	622	646	......	588	632	......	805	601	613	576	745	669
	Points....	82	85	70	91	67	......	85	70	......	82	100	85	94	56	83.0
	P. per min.	6.0	7.1	6.9	8.8	6.2	......	8.7	6.6	......	11.1	10.0	8.3	9.8	4.5	8.12
Nov. 17	Time.....	647	630	399	487	601	......	542	758	......	636	518	535	627	730	575
	Points....	97	82	76	100	46	......	100	61	......	85	88	100	85	88	90.1
	P. per min.	9.0	7.8	11.4	12.3	4.6	......	11.1	4.8	......	8.0	10.2	11.2	8.1	7.2	9.63
Dec. 15	Time.....	(2)	464	441	529	668	......	490	677	......	584	469	520	504	515	502
	Points....	(2)	94	91	91	67	......	88	76	......	91	94	100	76	88	90.3
	P. per min.	(2)	12.2	12.4	10.3	6.0	......	10.8	6.7	......	9.4	12.0	11.5	9.1	10.1	10.9
1918. Jan. 5	Time.....	710	718	418	491	689	1152	(2)	......	1548	662	484	576	497	854	600
	Points....	79	79	64	97	60	31	(2)	......	28	91	94	94	85	100	87.0
	P. per min.	6.7	6.6	9.2	11.8	5.2	1.6	(2)	......	1.1	8.3	11.6	9.8	10.3	7.0	9.02
Normal av.	Time.....	767	650	466	590	651	1152	646	770	1548	770	589	582	551	726	841
	Points....	87	85	77	95	60	31	93	61	28	86	88	95	84	82	87.0
	P. per min.	6.9	8.1	10.0	10.0	5.5	1.6	9.2	5.1	1.1	8.2	9.7	9.9	9.3	7.0	8.76
Jan. 13	Time.....	543	412	424	455	.....	822	572	......	1206	747	499	478	456	789	538
	Points....	91	94	67	100	.....	64	74	......	49	88	97	91	91	76	86.9
	P. per min.	10.1	13.7	9.5	13.2	.....	4.7	7.8	......	2.4	7.1	11.7	11.4	12.0	5.8	10.2
Jan. 19	Time.....	535	452	996	415	.....	470	503	......	1137	556	519	452	397	530	536
	Points....	97	82	71	100	.....	64	88	......	37	100	74	100	85	85	88.2
	P. per min.	10.9	10.9	4.3	14.5	.....	8.2	10.5	......	2.0	10.8	8.6	13.3	12.8	9.6	10.6
Jan. 27	Time.....	516	471	427	430	.....	872	561	......	902	653	410	375	375	562	478
	Points....	100	94	70	94	.....	56	91	......	40	85	88	95	76	79	87.2
	P. per min.	11.6	12.0	9.8	13.1	.....	3.9	9.7	......	2.7	7.8	12.9	15.2	12.2	8.4	11.3
Low-diet av.	Time.....	531	445	616	433	.....	721	545	......	1082	652	476	435	409	627	517
	Points....	96	90	69	98	.....	61	84	......	42	91	86	95	84	80	87.4
	P. per min.	10.9	12.2	7.9	13.6	.....	5.6	9.3	......	2.4	8.6	11.1	13.3	12.3	7.9	10.7

[1]No time record secured through mistake. [2]Subject absent because of illness.

time required to fill out the blank ranged from 428 to 1,027 seconds (see *Fre* and *Pec*); the average for the 10 subjects was 686 seconds. The total number of points made ranged from 52 to 100 (see *Kon* and *Bro*); the average for the 10 men is 74.6. The average number of points per minute, which is a combination result for time and accuracy, ranges from 3.6 to 12.3 (*Pec* and *Bro*), with an average of 6.99. *Bro* made a particularly good showing; he completed the blank in a comparatively

short time, without errors or erasures, hence his score is comparatively high. Two other subjects, *Fre* and *Tom*, were faster, but they made a number of errors, particularly the latter, and so reduced considerably what might be termed their "efficiency" result. *Pec* was slow, and somewhat inaccurate, hence his combination score for points per minute is small, being 3.6.

Considerable improvement may be expected in successive performances of this kind of task. A comparison of the low-diet averages shown at the bottom of table 189 with the figures for September 29, which have just been considered, reveals the fact that the improvement was marked. The average for the 9 sessions, October 13 to February 2, inclusive, show total time results ranging from 384 with *Pea*, to 725 seconds with *Pec*, who was noted to be the slowest on September 29; the average for the 10 men was 500 seconds, a reduction in time of about 25 per cent from the first trial. The range for the total number of points made in the test had become smaller, being 71 to 95. It could hardly be expected that any subject would make absolutely perfect records throughout. *Bro*, who made 100 points on September 29, did so only two other times out of the nine following experimental sessions. The average number of points for the squad during the reduction period was 83.2, a gain of about 10 per cent. The number of points per minute ranged from 6.3 with *Pec* to 13.3 with *Pea*, with an average of 11.1, representing a gain of approximately 60 per cent.

Squad B (see table 190) in their first experiment with this test (October 6) averaged a longer time to complete the tasks, requiring 860 seconds as compared to 686 seconds for Squad A. Their total average score was, however, 10 points better than that of Squad A, 84.6 compared to 74.6 points. Their combined score in points per minute, due to the longer time required to fill out the blank, was 0.9 lower, *i. e.*, 6.11 as compared with 6.99 points for Squads B and A. In the averages for the 5 normal sessions and for the 3 low-diet dates, Squad B shows less efficiency than Squad A in the performance of this test.

The comparison in points per minute for the 10 men in each squad and for the successive experiments is conveniently shown in figure 123. The chief characteristic of these curves is the rapid improvement; the irregularities are no larger than those commonly shown with such measurements. Squad B presents a rapid and uninterrupted improvement in the first four experiments; the depression on January 5 is coincident with the return from the Christmas vacation and also consistent with the findings in several of the other measurements for this date. During the low-diet period, Squad B continued to make improvement but very slightly. The change from 7.0 of September 29 to 8.6 of October 13 with Squad A is found to be not quite so large as the percentage change made by Squad B between their first and second

experiments. It must be noted, moreover, that in the case of Squad B, the two experiments were separated by 4 weeks instead of 2 weeks, as with A. The depression on October 27 is caused in part by the poor records of *Mon* for time and for accuracy. (See table 189, which shows *Mon's* records on this date were for time, 1,355 seconds, total number of points, 51, and points per minute, 2.3.) If this subject were omitted from the average, the figure would be 8.2 points per minute, which would be much more nearly in line with the value shown for October 13, but slightly lower. Improvement is very rapid in the next three sessions, reaching its maximum on December 8. This maximum is

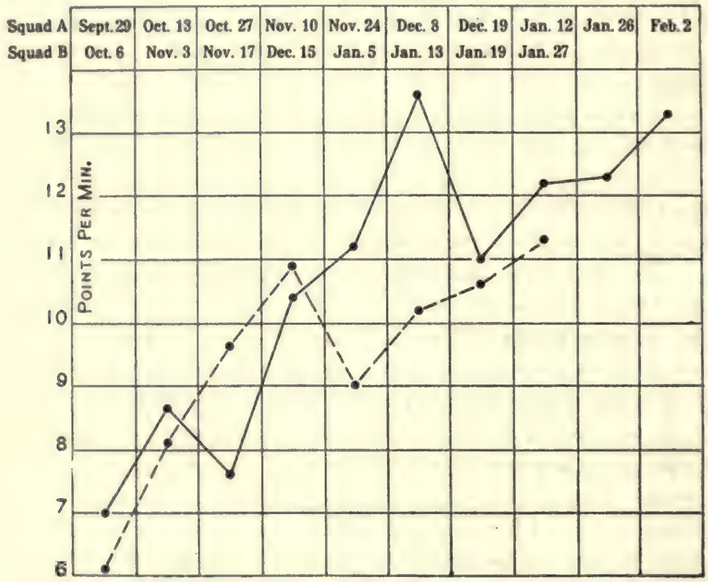

FIG. 123.—Accuracy in performing the clerical tasks.
Solid lines represent Squad A, broken lines Squad B.

largely due, perhaps, to the fortunate circumstance that on that date three of the subjects, *Bro*, *Gar*, and *Vea*, chanced to have perfect records, with the result that their points per minute were in each case the highest they had made at any time in the experiments. Giving their records in order as named, they were 16.3, 14.2, and 16.9 points per minute. The marked depression on December 19 can not be associated with any particular dietetic change, for the men were fairly comfortable at this period of the experiment, as is clearly indicated by their introspections recorded in other sections of this report. The improvement was continued on January 12, 26, and February 2, although not on the high level of December 8. The results, as with several other of our measurements, are complicated. They indicate that Squad B during the three weeks of low diet, and Squad A during the first four weeks of low diet, improved but slowly in their efficiency in the clerical tests.

SUMMARY OF PSYCHOLOGICAL RESULTS.

The previous discussions of neuro-muscular measurements have not depended upon introspective accounts. We have in each instance made the measurements as objective as possible, and have given the essential data and the best available material as comparison standards for averages. It seems unwise to attempt a summary table or diagram. Many of the measurements do not lend themselves readily in this case to a numerical statement of differences on account of the small amount of normal material which was actually secured from Squad A, and it is this group in which we are most deeply interested, since it was with them that the prolonged low diet was tried. While we may compare the results of Squad A on low diet with the normal values for Squad B and for other groups of men, yet it hardly seems permissible to subtract for differences and to claim that these state in terms of magnitude the effects of the reduced diet. In a few cases in which changes associated with the low diet have been definite and progressive as, for example, in the eye movements, it was found possible to compare the performance of the first of the experiments with that shown on the later dates and to state such differences in terms of per cent change. In general, we have had to be satisfied, under the circumstances, with statements of the direction of the effect, when such has existed, and secondarily with general statements as to the probable amount of the change.

The most significant results found for the neuro-muscular tests are given in simplest form for comparison. Opposite each measurement, named and numbered in order, there is a brief statement of the low diet effect, or of the apparent lack of such an effect.

(1) Accuracy in tracing. Less accurate work and less rapid improvement.
(2) Pitch discrimination. Slightly poorer near the threshold.
(3) Number cancellation. Slower improvement.
(4) Addition. Slower improvement in accuracy.
(5) Memory span. No certain change.
(6) Strength of grip. Definitely lowered.
(7) Pulse with exertion. Lowered level of pulse-rate, nothing pathological.[1]
(8) Patellar reflex. Slightly depressed.
(9) Eye reactions. Not significantly changed.
(10) Word reactions. Not significantly changed.
(11) Number reactions. Not changed.
(12) Visual threshold. Efficiency not decreased.
(13) Electrical threshold. Less sensitive and less improvement.
(14) Eye movements. Slower speed.
(15) Finger movements. Slower speed, no indication of quicker fatigue.
(16) Maze performance. Not significantly changed.
(17) Clerical tasks. Slower improvement.

From this review of the results with the neuro-muscular measurements it appears that there was some disturbance in motor coordination and in muscular performances generally. The reactions, thresholds, and discriminations show less definite change. The same is true for the more complex processes involved in memory, maze performance, and clerical tasks. In some of these processes not distinctly muscular there appeared to be slower improvement under the low-

[1]See section on pulse-rate, p. 415, for results.

diet conditions than would, according to our other standards, be expected from these men. These changes in performance and in practice, *i. e.*, learning with successive performances, are most prominent at those periods when the subjects are actually losing weight. The changes, even at these times, are not what could be considered as at all pathological. Just as the weights of the subjects, when they had reached their low level, were still within what are commonly considered by actuarial authorities to be normal limits, so the changes found in the neuro-muscular processes usually seem no larger than the normal range of results for supposedly normal men would permit. It is difficult to estimate how much of a decrement may take place, for example, in the muscle coordinations of a subject, and still not seriously interfere with his usual activities. Theoretically, for competitive, high-grade work, no decrement should be permitted, and therefore no conditions allowed which will operate in the direction of such a decrement. Practically, and under urgent circumstances, an individual may adjust himself to a rather wide range of neuro-muscular changes accompanied by varying conditions or degrees of physiological and psychological comfort and well being and at the same time do his usual work in a way which to others, at least, is not sensibly inferior.

REDUCED DIET AND SEX EXPRESSION.

Prolonged reduced diet with resulting change to a lower nutritional level might conceivably have some important sociological bearings. It might be asked, for example, if there were under these circumstances any change in the sex interest and desires. Under ordinary conditions trustworthy introspective statements on this problem would be exceedingly difficult to obtain. This is obviously due in large part to the prudishness of our education in regard to sex matters. The ordinary individual is not willing to reveal the facts of his own sex life and finds difficulty in taking an objective attitude in reviewing them. If asked direct questions, many a man would take the attitude that he was insulted and would either refuse the information or evade the truth.

It is important to emphasize the difficulties which usually surround the collection of trustworthy sex data, for it so happens that they contrast sharply with those which were fortunately present in our research. The attitude of the Young Men's Christian Association on knowledge of sex is well known. No other organized group of men has treated the subject in a more straightforward and frank manner. Both in the schools over which they have control and in their public service for men in clubs and gymnasiums, they have labored to establish a sane view of these things and to place private and social hygiene on a sure footing. At the International Y. M. C. A. College at Springfield, especially, it has been recognized that each secretary and physical director must have a sound and wholesome attitude regarding these

important matters if he is to be of maximum service to the Young Men's Christian Association. Thus the subjects of our investigation were accustomed to regard and discuss sex matters from a different point of view than would be the case with most groups of men or, we might say, with almost any other group of men. These men were neither prudish nor vulgar-minded. They were a clean group of honest, virile men and with no venereal diseases.

On February 8 and 9 one of us was in Springfield for the purpose of interviewing the men of both squads with regard to changes from reduced diet to the uncontrolled eating. An individual interview was arranged with each man. The conditions were entirely appropriate to holding such personal interviews. Each conference was begun by discussing the topics of clothing and cold, ability for physical and mental work, and the condition of the stomach and bowels, on the uncontrolled diet in contrast to the conditions prevailing during the experiment. The men discussed these topics freely and full notes were made. Finally, we asked if in the contrast between low diet and uncontrolled eating they had noticed any change in the sex desires or interest. Before the men could reply, it was pointed out that suggestion and introspection are particularly prominent elements influencing the sex factor, and therefore it was not deemed wise to question on this topic during the experiment. On the other hand, since the subject has a large possible importance physiologically and sociologically, it could reasonably be mentioned at this point. Any personal candid opinion the subject might be willing to express concerning his own case would be appreciated and considered as personally confidential.

Following the first direct answer by the subject, he was asked to make the matter specific in his own case under such topics as nocturnal seminal emissions; tendency to erection; desire for and sex appeal at dance and occasions of association with women; sex appeal of shows, pictures, and books; and any other conditions peculiarly individual where sex might be a factor. Furthermore, he was asked to give any comments concerning dreams. Every effort was exercised to make the questions neutral. We could in no wise anticipate what would be revealed by the group of interviews. It is gratifying to record that not one of the 24 subjects took the matter as a joke or objected to having notes made from his comments.

The detailed evidence is published in full elsewhere,[1] and is peculiarly uniform. The usual statement was about as follows:

"In my own case I am convinced that sex desires were much less prominent during the low-diet period than under normal conditions. I had no attractions to the opposite sex and did not care to be with them. This condition in

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[1]Miles, The sex expression of men living on a lowered nutritional level, Journ. Nervous and Mental Disease, 1919, **49**, p. 208.

myself surprised me greatly. Nocturnal emissions and erections were less frequent while on the diet.[1] I do not recall any sex dreams. There were a few dreams of food."

Although the interval on full diet between the close of the experiment and the date of the interview was not long, many of the men reported having observed a distinct return to normal sex interest with the uncontrolled eating. This was manifested particularly in the desire to associate with women. Suddenly and coincident with the uncontrolled eating the opposite sex had become very attractive. The men insisted that they had essentially as much to do and to occupy their attention outside of the experimental period as during the experiment and that the change must be an effect of the reduced diet. Some of the men had spoken with room-mates or other near associates concerning this change which they observed in themselves during the period of the experiment. The element of suggestion undoubtedly played some part, but on the other hand a good many had never before the interview considered the topic with anyone, although they had recognized changes in themselves and had given some thought to them.

We have emphasized the favorable conditions surrounding the collection of these data. We believe that the self-observations of the men are, on the whole, trustworthy. It is clear that they show a decrease in sexual interest and expression, which, according to some of the men, reached the point of obliteration with the lowered nutritional level incident to the prolonged reduced diet, and that, furthermore, there was a prompt return to normal conditions with the uncontrolled feeding. The accounts of the two squads, A and B, were in agreement.

These results appear to us of considerable significance. Any dietetic régime which, even though it affects the external appearance and performance of an individual but little, definitely lowers the tone of the sex instinct, causing one sex to take but little interest in the other, would seem to be disadvantageous to society if indefinitely prolonged and no adjustments were made in the sex instincts. Our data indicate that nature demands a rather high metabolic level for the normal functioning of sex in man. Admittedly we are venturing somewhat into the field of speculation in discussing the matter from this more generalized point of view. But one thing is sure: no sweeping general conclusion about the lowered nutritional level found in this investigation may disregard the effect on the sex expression.

We are by no means on new territory when we connect sex and the metabolic level. Riddle[2] and other workers find with animals that

[1]It is to be recorded that since many of the men had to rise at an earlier hour than was their usual habit, the bladder was seldom as full as might normally be, and since frequently this is associated with erection, this influence must not be entirely neglected in weighing the evidence.

[2]Riddle, Lectures on heredity, Washington Acad. Sci., 1917, p. 319.

sex is closely associated with metabolism and is probably more or less dependent on the metabolic level. These investigators have shown that by modifying one they may modify the other. It is commonly believed that the sex instinct is stronger in men than it is in women. The large amount of metabolism data from this laboratory and other institutions has proved that the metabolism of men is higher than that of women. It is not, therefore, illogical to believe that a lowered metabolism in men may reduce or even obliterate sex interest.

PHYSICAL ACTIVITY AND ENDURANCE.

The important relationship between muscular work and total metabolism made it incumbent upon us to obtain all possible information with regard to the relative physical activities of these groups of men and their college mates. The diet was to be reduced by design. If the physical activity were likewise considerably reduced, it is obvious that the diet might still be a maintenance diet without a material alteration in the general condition of the body. While the main criterion was to be a reduction in weight of 10 per cent, which would inevitably take place if the supply were materially less than the demand, it still would definitely disturb the relations of the experiment if the subjects reduced the physical activity appreciably. The men were repeatedly instructed and, indeed, urged to keep their bodily activities as nearly normal as possible. It was impressed upon them that the aim of the experiment was to study the effect of a reduced diet upon the efficiency of a group of men in carrying out the ordinary activities of the collegiate life. If they voluntarily and deliberately reduced these activities at the beginning they would not be fulfilling the prime condition of the experiment and would seriously vitiate the results.

These men were all college students and had the regular college program to carry out. This involved a certain amount of walking to and from classes in the different buildings and to the main dining-hall for the several meals, also the gymnasium work prescribed in certain college courses. Furthermore, as with most college students, walking was a regular form of exercise and recreation outside of the prescribed college work.

One development we did not anticipate was the fact that in many instances the men made special efforts to reduce the weight at the beginning of the experiment. To hasten the loss of fat and thus reach the 10 per cent level quickly, they indulged in unusually strenuous and prolonged exercise. The subjects reasoned that the sooner the desired weight reduction was attained, the sooner they would receive larger amounts of food to hold them at this level. This same increase in physical activity appeared several times throughout the course of the experiment, particularly after the uncontrolled Sundays, the short Thanksgiving recess, and the Christmas vacation.

Two attempts were made to secure quantitative estimates of the daily physical activity of these men. It was believed that at least a rough estimation could be obtained by means of pedometer records. Accordingly, each man was supplied with a pedometer which he wore continuously, and daily readings were recorded. When used for level walking over reasonably smooth roads, and particularly when a measure of the length of step has been obtained in walking over a measured distance, the pedometer gives a very satisfactory record of distance walked. It was recognized at the outset, however, that in using these pedometers these men must record activities other than the simple up-and-down motion of the body incidental to ordinary level walking. Accordingly our pedometer records should be looked upon primarily, not as the summation effect of so many up-and-down motions of the body, but as the summation of a large number of body-motions differing materially at times in intensity, and thereby in energy requirements.

TABLE 191.—*Daily record of walking (pedometer) of Vea during period of reduced diet.*

Date.	Miles walked.	Date.	Miles walked.	Date.	Miles walked.	Date.	Miles walked.
1917.							
Oct. 6– 7	8.50	Nov. 5– 6	5.00	Dec. 5– 6	5.25	Jan. 3– 4	10.00
7– 8	8.00	6– 7	4.00	6– 7	5.50	4– 5	11.00
8– 9	6.75	7– 8	6.00	7– 8	4.25	5– 6	9.00
9–10	7.75	8– 9	6.00	8– 9	5.00	6– 7[2]	1.00
10–11	6.00	9–10	7.00	9–10	8.50	7– 8	5.50
11–12	6.00	10–11	5.00	10–11	4.50	8– 9	3.25
12–13	8.00	11–12	4.75	11–12	7.25	9–10	4.50
13–14	5.00	12–13	6.25	12–13	7.75	10–11	7.50
14–15	7.00	13–14	2.25	13–14	4.50	11–12	4.75
15–16	6.00	14–15	6.00	14–15	6.25	12–13	5.50
16–17	3.50	15–16	6.50	15–16	9.25	13–14	7.25
17–18	7.00	16–17	9.00	16–17	4.25	14–15	1.50
18–19	4.00	17–18	4.00	17–18	5.25	15–16	10.00
19–20	9.25	18–19	3.25	18–19	7.00	16–17	5.50
20–21	7.25	19–20	10.25	19–20	3.75	17–18	5.50
21–22	6.00	20–21	7.25	20–21[2]	4.00	18–19	7.50
22–23	5.00	21–22	10.00	21–22	6.00	19–20	5.25
23–24	5.00	22–23	5.00	22–23	11.50	20–21	5.00
24–25	6.50	23–24	5.75	23–24[3]	.....	21–22	4.75
25–26	2.50	24–25	5.00	24–25	12.50	22–23	8.00
26–27	8.50	25–26	3.75	25–26	7.50	23–24	4.50
27–28	6.50	26–27	3.50	26–27	13.00	24–25	7.75
28–29	6.00	27–28	7.25	27–28	16.00	25–26	3.50
29–30	7.00	28–29	10.50	28–29	17.25	26–27	7.50
30–31	2.50	29–30[1]	16.50	29–30	17.00	27–28	4.00
Oct. 31–Nov. 1	8.25	Nov. 30–Dec. 1	16.00	30–31	8.50	28–29	4.25
Nov. 1– 2	3.50	Dec. 1– 2	13.50	Dec. 31–Jan. 1	30.25	29–30	7.75
2– 3	8.00	2– 3[1]	10.00	1918	......	30–31	4.25
3– 4	9.00	3– 4	9.25	Jan. 1– 2	12.00	Jan. 31–Feb. 1	4.00
4– 5	4.50	4– 5	3.25	2– 3	9.00	Feb. 1– 2	4.50

[1] Thanksgiving recess, Nov. 29 to Dec. 2, inclusive; diet uncontrolled during this period.
[2] Christmas recess, Dec 20 to Jan. 6, inclusive; diet uncontrolled during this period.
[3] *Vea* ill Dec. 23–24.

The pedometers used were all of the same make and were set at the uniform step of 27 inches employed in the factory setting; no attempt was made to adapt the setting to the individual. The pedometer records for the entire group of men are reasonably complete. It is obviously impracticable to report the pedometer readings for the individual men for each day of the entire experiment, hence in table 191 we give only a typical set of records for one subject, *Vea*, to illustrate the general method of recording.

Here again the need of normal data is apparent, for unfortunately the pedometers were not given to the men in Squad A until after the reduction in diet took place. For these men, therefore, it will be necessary to use normal data subsequently secured with Squad B and other volunteer members of the undergraduate body of the college for comparison with the values obtained during the low diet.

A general examination of table 191 shows that, excluding the Thanksgiving and Christmas recesses, *Vea* walked daily on the average, in October 6.3 miles, in November 6.0 miles, in December 5.9 miles, and in January 5.6 miles. During the Thanksgiving and Christmas recesses, there was a great increase in the miles walked per day, the distance walked amounting on December 31 to January 1 to 30[1] miles. The general picture of this pedometer record shows that *Vea* did not alter his activity materially as the experiment progressed and the low diet continued.

VARIATIONS IN ACTIVITY AS RECORDED BY THE PEDOMETER FROM WEEK TO WEEK.

Although table 191 shows clearly that *Vea* varied considerably in his activity from day to day, especially in the uncontrolled-diet periods, it is more important for general conclusions to secure average values for each individual throughout the experiment. In table 192 we have tabulated the number of miles, as recorded by the pedometer of each member of the squad, from the beginning to the end of the experiment. These are expressed as miles per day and are usually based upon the average for the weekly periods. Walking records were made by all the men in the squad during the Thanksgiving recess; records were also made during the Christmas recess by 6 men who volunteered to use the pedometers throughout the entire period, even when away from Springfield. Striking differences in the distance walked are evident with the various individuals. In the first 5 days, October 6 to 11, we have a mileage per day ranging from a maximum of 14.2 miles with *Pec* to a minimum of 4.5 miles with *Gar*. The average for all subjects in this period is 8.16 miles per day.

[1]This unusually high value agrees very well with the actual distance between two towns walked by *Vea* on this day.

Attention has been called to the fact that the individual records for *Vea* (see table 191), showed no pronounced tendency for a progressive reduction in the total distance walked during the four months of the experiment. This same statement applies to the average record for each subject and for the total average for the group of subjects as shown in table 192. This generalization of itself is justification for considering the pedometer records seriously. The most conspicuous exception is the case of *Moy*, whose record decreases with fair regularity in the first 6 weeks, *i. e.*, the pronounced transitional phase of the experiment, from an initital value of 9.20 for October 6 to 11 to 3.11 for November 15 to 22. The records made during the Thanksgiving recess (November 29 to December 2) and the Christmas recess (December 20 to January 6) are of interest, but not directly comparable with the other records shown in the table, since at these times the men naturally had freedom from college and classroom work and were at liberty to walk about more than usual. With the exception of three subjects, *Moy*, *Pec*, and *Vea*, all of the men show higher records (exclu-

TABLE 192.—*Weekly record of walking (pedometer)—Squad A, reduced diet.*
[Average miles per day.]

Dates.	Bro.	Can.	Kon.	Gar.	Gul.	Mon.	Moy.	Pea.	Pec.	Spe.	Tom.	Vea.	Av.
1917.													
Oct. 6–11	7.80	7.50	[1]6.60	4.50	11.40	5.40	9.20	9.00	14.20	8.50	6.40	7.40	8.16
Oct. 11–18	8.57	7.43	[1]6.86	3.79	10.43	4.46	6.79	8.29	12.00	10.11	7.42	6.07	7.69
Oct. 18–25	5.79	6.36	[1]5.14	4.39	10.07	4.21	5.86	7.14	6.21	6.96	5.71	6.14	6.17
Oct. 25–Nov. 1	6.29	7.29	4.25	3.39	9.72	4.64	4.25	7.29	5.75	6.14	5.39	5.89	5.86
Nov. 1– 8	4.29	6.25	3.64	4.07	9.86	4.79	4.71	8.43	6.50	9.86	6.50	5.71	6.22
Nov. 8–15	5.30	6.86	4.04	5.32	8.11	3.82	3.54	7.36	5.96	9.50	7.38	5.32	6.04
Nov. 15–22	6.68	10.64	4.39	8.00	11.88	5.14	3.11	7.93	10.17	6.00	7.64	7.18	7.40
Nov. 22–29	6.96	5.29	3.65	3.73	6.54	5.76	4.09	8.00	11.67	5.36	5.71	5.82	6.05
Nov. 29–Dec. 6[2]	10.00	8.25	5.03	5.68	10.40	7.89	7.82	8.07	9.65	9.64	7.93	10.54	8.41
Dec. 6–13	7.32	6.04	4.21	7.96	9.32	4.64	5.07	7.36	5.00	6.13	5.50	6.11	6.22
Dec. 13–19	9.13	6.88	4.29	6.63	8.50	5.88	6.42	10.25	9.86	.....	6.35	6.08	7.30
Dec. 20–Jan. 7[3]	3.87	.....	.....	....	7.78	6.05	5.46	5.66	.....	.....	....	11.07	6.65
1918.													
Jan. 7–14	7.46	5.54	.....	4.20	7.46	5.50	4.75	4.18	5.56	.....	....	5.46	5.57
Jan. 14–21	7.36	5.39	4.11	6.79	10.93	5.39	5.89	6.71	9.54	.....	3.50	5.75	6.49
Jan. 21–28	6.39	6.89	5.36	5.68	7.75	6.04	5.25	6.79	7.04	.....	2.96	5.71	5.99
Jan. 28–Feb. 2	10.95	6.85	5.55	5.69	11.30	6.06	7.05	4.94	8.35	.....	3.60	4.95	6.84

[1]*Fre* served as subject from Oct. 6 to 25, when his place was filled by *Kon*.
[2]Thanksgiving recess, Nov. 29 to Dec. 2, inclusive.
[3]Christmas recess, Dec. 20 to Jan. 6, inclusive.

sive of those made in vacation periods) at some time after the first week. With *Spe* the highest record is for the second week, October 11 to 18. Nine of the 12 men—*Bro, Can, Kon, Gar, Gul, Mon, Pea, Tom* and *Vea*—show their highest average records at a date following

November 15. On this date the food reduction had been in force for over 40 days,[1] and the ingestion had actually been somewhat increased for maintenance.

From the total averages for the 12 men, it will be seen that the highest average, 8.41 miles, falls at the time of the Thanksgiving recess when the men were free from college duties and were on an uncontrolled diet. That these conditions made a difference in the activity is certain. There are variations in the total weekly averages, but in general these can not be regarded as large. The extreme range, omitting the Thanksgiving recess, is from 5.57 to 8.16 miles per day per man. The latter figure comes at the beginning of the experiment, when possibly psychological factors and weather conditions would naturally favor a large record. Excluding the Thanksgiving and Christmas recesses, the average values for the entire squad are October, 7.0 miles, November, 6.4 miles, December, 6.8 miles, and January, 6.2 miles per day.

The striking increase in the miles walked by *Vea* during the Christmas vacation, combined with the fact that he was at this time on uncontrolled diet, led us to think that throughout the entire research there might be some close correlation between the actual energy of food taken and the miles walked, *i. e.*, with more food there was more inclination to walk. It was found that not only *Vea* but practically all the members of Squad A apparently showed a correlation between these values in that a somewhat liberal diet was coincidental with a greater amount of walking. That this is a case of direct cause and effect is by no means proved. The more liberal diet was almost invariably associated with absence from college, *i. e.*, the Thanksgiving and Christmas recesses, with more time available for and possibly inclination for walking.

FACTORS INFLUENCING THE PEDOMETER RECORDS.

No great significance should be attached to the pedometer readings without due consideration of the factors influencing them, as otherwise they might lead to false conclusions. As pointed out earlier, the pedometer actually records the up-and-down motion of the body and is supposed to be used exclusively for indicating the distance walked in horizontal forward progression. As previously stated, from the various activities of the men in these squads, we are certain that the pedometer readings may not be directly considered as so many miles walked, especially when we are attempting to attribute a quantitative energy value to the several readings. In other words, each unit recorded on the pedometer may by no means have the same calorific significance. Thus, in going upstairs, each step requires much more energy than a step in

[1]Four of the subjects, *Kon*, *Mon*, *Moy*, and *Tom*, show their highest walking record in the Thanksgiving recess, and *Vea* his surprisingly high record during the Christmas vacation. As may be seen from his individual records in table 191, on December 31 *Vea* took an unusually long walk. The second highest record for *Vea* was during the Thanksgiving recess.

level walking, and yet it would be recorded as one unit by the pedometer. Indeed, with level walking a marked change in the character of the terrain would alter the calorific value of each pedometer unit. Walking on a smooth and level sidewalk would have one value; walking over slippery ice would have a value which would be the resultant of a shorter step and accompanying increase in the leg tension for balance. These pedometers were worn the entire day. The men were cautioned, when riding in automobiles or trolley cars, to be sure that the motion of the vehicle did not cause registration. These false records, however, probably play very little rôle in the series as a whole. It is perfectly conceivable that the activity indicated by a half hour of wrestling or calisthenic exercise in the gymnasium, with jumps up and down, is not at all comparable to the equivalent number of pedometer units registered while walking, hence, it must be recognized that the pedometer does not differentiate in the character of these various units.

We must further consider the factors contributing to activity in general, as recorded by the pedometer. These may be summed up as follows: First, the novelty or the psychological effect is a stimulus to increased record. This would be expected to appear, if at all, in the first week of wearing the instrument. The further possibility of a psychological effect with the squads expressing itself in a desire to make a better showing at the start than a competitive squad should also be considered. A second factor would be weather conditions. With fair weather, such as that obtaining in early fall, walking would be more pleasant than in bad weather, such as might occur later in the season. During icy conditions there would be less tendency for walking but, as pointed out previously, there would follow a distinct change of gait, and possibly a shortening of step with a consequent more rapid registration of pedometer units. It should likewise be remembered that with this shortened step on an icy walk there would be a greater consumption of energy for walking the same distance. Third, with time available for walking so limited during the busy college year, relaxation and recreation would be first sought in walking, as was clearly shown by the records for the Thanksgiving and Christmas recesses. Fourth, the state of nutrition would also affect the inclination for walking.

As has been pointed out, there is a reasonable relationship between the quantity of walking registered by the pedometers and the net available energy in the diets for corresponding periods of time. And yet on close inspection we can not convince ourselves that this is of special significance, because several other factors must be taken into consideration, such as the psychological factor mentioned above and the time available for walking in the vacations. On the assumption, however, that to walk a horizontal mile requires 60 calories, it is very clear that the differences in miles walked at the different stages

is by no means sufficiently large to in any wise account for the actual changes in the net energy consumption. On the other hand it is true that horizontal walking is the easiest part of a man's activity to maintain up to a normal standard amount under conditions of physical weakness and discomfort. A man can walk with comfort and pleasure when he would avoid running and exercise more strenuous than walking, unless prompted by necessity or some special motive. It seems probable, therefore, that if we had quantitative estimates for physical activity more strenuous than walking, these might follow the fluctuations found with the walking, and the variations in activity might conceivably be larger. It is not surely indicated that they would be large enough, however, to account for the energy differences from period to period of the experiment. Such correlations between activity and energy intake are not definitely proved in this research to be physiological necessities. The influence of mental attitude, ranging from depression, with much restricted diet, to the feeling of euphoria, with more liberal diet, would make for a similar correlation.

In interpreting the records of activity and in attempting correlations with diet, clear distinction must be made between those periods in the research that should more strictly be considered as transitional periods and those that are maintenance periods. With Squad A we have at the beginning of the experiment a distinctly transitional period. Immediately after the Thanksgiving recess we have a period of greatly reduced diet to overcome the excess eating during this vacation. A similar short transitional period appears in the early part of January. With Squad B the entire reduced diet period must be considered as a transitional period. Strictly speaking, the two periods of preeminently maintenance levels for Squad A are those about the middle of December and the latter part of January.

For purposes of analysis it is quite unfortunate that the transitional period in the early fall was coincidental with the period of fair weather, thus contributing towards considerable walking. After October 18 it is apparent from the figures in the last column of the table that there is no pronounced tendency for these subjects to reduce materially their physical activity, at least as indicated by the pedometer records. It should still be pointed out, however, that this table does not indicate the probable number of miles that these men would have shown in the week prior to dietetic restriction.

PEDOMETER CONTROL WITH SQUAD B ON NORMAL DIET.

To secure important evidence of the probable activity as recorded by the pedometer of a homogeneous group of college men not on diet, arrangements were made for observations on Squad B during the period of December 13 to 19. The homogeneity of these squads is, of course, difficult to determine with strictest accuracy. They were

about evenly divided in their make-up between men who were taking the course in physical education and those who were taking the secretarial course. As a matter of fact, Squad A had, excluding *Fre*, 7 men taking the physical course and 5 taking the secretarial course, while with Squad B, 9 were taking the physical course and 3 the secretarial course. Undue prominence, however, should not be given to this classification, for it is by no means sure that the activities of the men taking the physical course were very much, if any, greater than those of the subjects taking the secretarial course.

COMPARISON OF PEDOMETER RECORDS, SQUAD A, WITH THOSE FOR SQUAD B ON NORMAL DIET.

The normal values obtained for Squad B are recorded in the first line of table 193, with an average of 6.24 miles per day. Comparing this average value, obtained when the subjects were on normal diet, with those obtained with Squad A on reduced diet (see table 192) it can be seen that this is not far from a roughly average figure shown by the latter squad. If anything, it is slightly lower than those obtained when Squad A was at maintenance level, namely, December 13 to 19, and the latter part of January. We believe that this is tolerably good evidence that Squad A was not exercising less, at least so far as the pedometer records are concerned, than the average college student of the undergraduate body. Emphasis should again be laid upon the fact that Squad B was on normal diet, as the men were not put upon reduced rations until January 8. The evidence, therefore, as supplied by the pedometer records, is clearly to the effect that Squad A, after the first two weeks, maintained a level of walking which was perfectly comparable, even when on low diet, to that maintained by Squad B on a normal diet with very much larger energy content.

While the closest attempt to secure quantitative measurements of physical activity by means of pedometers leads to the above findings, yet, in view of the defective nature of the pedometer units, an analysis of the probable physical activities, particularly those other than walking, is essential before the final decision can be made as to whether or not Squad A materially altered their physical activity as compared to that of the average undergraduate in the Y. M. C. A. College.

PEDOMETER RECORDS FOR SQUAD B WITH REDUCED DIET.

The pedometer records for Squad B are given in table 193, together with the normal values obtained on December 13 to 19. In considering these, it is important to bear in mind that the observations made on Squad B comprise solely those during a transitional period. The average number of miles during the first week of reduced diet is practically uniform with that on normal diet, but the pronounced fall in the subsequent two values is worthy of emphasis and is clearly to be ascribed to the very severe reduction in diet which took place.

TABLE 193.—*Weekly record of walking (pedometer)—Squad B.*

[Average miles per day.]

Dates.	Fis.	Har.	How.	Ham.	Kim.	Lon.	Sch.	Liv.	Sne.	Tho.	Van.	Wil.	Av.
Normal diet:													
Dec. 13–19, 1917...	....	8.70	8.83	9.60	....	4.15	....	6.21	4.40	5.94	3.83	4.50	6.24
Reduced diet:													
Jan. 8–15, 1918...	3.71	5.25	10.55	6.29	5.17	12.17	....	8.71	4.79	6.29	2.71	3.39	6.28
Jan. 15–22, 1918...	4.43	3.54	6.00	6.36	4.25	7.79	3.29	4.33	3.13	4.43	4.36	2.61	4.54
Jan. 22–27, 1918...	5.20	3.45	5.25	4.63	4.88	6.50	5.38	6.00	3.50	3.56	5.55	2.25	4.68

ESTIMATES OF VARIOUS FORMS OF PHYSICAL ACTIVITY.

In addition to the pedometer readings, which were objective, we have a number of records which were made by the men in connection with their regular college work and for special purposes. Unusual attention is given at the International Y. M. C. A. College to courses on personal efficiency, and not a few of our men in both squads were members of a class which was called upon to report during a given week the actual number of hours spent in sleeping, at meals, dressing and undressing, in productive labor, and in what might be classified as "waste time." Thus they were more than ordinarily keen observers of their own physical activities.[1] As a result of an inspection of a number of the charts used by the men in these courses, a special form of record was prepared and given to all of the men in Squads A and B, to be filled out practically each day throughout the month of January. On these charts a statement was made as to the nature of the exercise, the general health, and the condition of the bowels. Since both squads were on diet during the month of January, a third volunteer squad of 12 men, selected from the student body, were requested to fill out a similar blank to indicate the general nature of the activities of the undergraduate not undergoing the special dietetic regulations, the prime object of this third set of records being to find if a difference existed between the regular college undergraduate and Squads A and B. Thus we have records for approximately 35 men, covering somewhat more than 2 weeks during the month of January.

It will be remembered that during January Squad B was upon a particularly low diet of about 1,300 or 1,400 net calories. It seemed desirable to note if the men in this squad instinctively lowered their physical activities as a result of the greatly lowered food intake. Consequently these observations are reported in rather extensive detail,

[1]To secure a rough estimate of the amount of time the men spent in activities more intense than walking, they were asked at dinner on the night of September 27, *i. e.*, before restriction in the diet began, to give an estimate of the hours spent per week in walking or more active exercise. These records, here expressed as daily values, are as follows: *Bro*, 3.6 hours; *Can*, 1.7 hours; *Fre*, 3.6 hours; *Gar*, 3.9 hours; *Gul*, 4.7 hours; *Mon*, 5.0 hours; *Moy*, 3.6 hours; *Pea*, 3.6 hours; *Pec*, 3.6 hours; *Spe*, 4.0 hours; *Tom*, 3.6 hours; *Vea*, 3.0 hours. This shows an average of 3.7 hours per day.

since these exercise records supply evidence, first, as to the relative activities of Squads A and B, and second, and perhaps more important, the relative activities between Squads A and B and a group of undergraduates not on restricted diet of any form. The observations on general health and condition of the bowels, which for the most part presented no particular phases, are omitted.

The blank furnished each of the men called for a subdivision of the hours per day spent in lying, sitting, and walking; an effort was made to differentiate the activity further by the inclusion of a record of exercise of greater intensity than walking. The time spent in lying obviously included that spent in bed, together with any other time that was so occupied, and does not necessarily mean the time asleep. The sitting involves sitting in the men's rooms, in class, at meal times, etc.

TABLE 194.—*Exercise records during reduced diet—Squad A.*

Date.	George A. Brown.				Kenneth B. Canfield.				Everett R. Kontner.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]	Lying.	Sitting.	Walking.	Exercise greater than walking.[3]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 11	8	9	7	......	......	......	......	......	......	......	......	......
12	8	11	5	......	7	13	4	......	8	12	4	......
13	8	14	2	......	9	11	4	......	8	15	1	......
14	8	12	2	2	10	11	2	1	8	15	1	......
15	9	11	2	2	8	10	6	......	9½	12½	1	1
16	7½	10½	4	2	7	12	4	1	9	12	3	......
17	8½	11	2	2½	8	13	3	......	8	13	3	......
18	8½	10	3	2½	7	12	4	1	9	12	3	......
19	8	12½	3	½	6	17	1	......	8	12	4	......
20	8	14	2	......	7	15	2	......	9	14	1	......
21	8	11½	2½	2	7	12	4	1	10	13	1	......
22	8	10½	2	3½	8	12	4	......	9	11	4	......
23	9	9	4	2	7	14	3	......	8	14	2	......
24	8	10½	4	1½	6	16	2	......	8	14	2	......
25	9	12	2½	½	8	13	2	1	6	16	2	......
26	8	12	4	......	9	13	2	......	7	14	3	......
27	8	14	2	......	8	14	2	......	9	13	2	......
28	7½	12½	2	2	9	12	2	1	8	13	3	......
29	8	8	6	2	7	13	4	......	8	14½	1½	......
30	7½	10	4	2½	7½	13	2	1½	......	......	......	......
31	8	11	3	2	8	12	4	......	9	13	2	......
Feb. 1	8	12½	2	1½	6	13	3	2	8	12	2½	1½
2	8	12½	3½	......	10	11	3	......	7	15	2	......
3	......	......	......	......	8	13	3	......	6	16	2	......
Av....	8	11¼	3¼	1½	7¾	12¾	3	½	8	13½	2¼	¼

[1]Chiefly "calisthenics" (marching, dancing, apparatus work) and ice hockey; also 3½ hrs. snow-shoeing, 25 mins. riding bicycle ergometer; "endurance test"; motion pictures.

[2]Gymnasium work and hockey, 25 mins. riding bicycle ergometer; "endurance test"; motion pictures.

[3]One hr. gymnasium work; 20 mins. riding bicycle ergometer; "endurance test"; motion pictures.

EXERCISE RECORDS FOR SQUAD A.

The records for Squad A are given in table 194. They were kept for most of the time from January 11 until February 2 or 3, inclusive. Although the men endeavored as far as possible to classify their activities, and it can be seen that commonly there was uniform regularity in so doing, it is obvious on individual days there may be rather gross deviations from the exact facts. On the whole, however, the picture of all members of Squad A may be taken as indicative of their activity during this period. The records in the table are given on the quarter-hour basis.

Lying.—An examination of table 194 shows that usually the men were lying not far from 8 to 9 hours per day. The exception to this

TABLE 194.—*Exercise records during reduced diet—Squad A*—continued.

Date.	Greyson C. Gardner.				Otto A. Gullickson.				Kirk G. Montague.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]	Lying.	Sitting.	Walking.	Exercise greater than walking.[3]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 11	......	......	......	......	5½	8	6	4½	7	8	9	......
12	9½	9	5½	......	8	10	6	......	7	5	12	......
13	8	12	4	......	6	11	5	2	5	12	7	......
14	9¼	6½	4¾	3½	4½	7	7½	5	4	7	10	3
15	8	8	2	6	3	11	4	6	7	6	8½	2½
16	10	6	5	3	5½	6½	7	5	8	7	7	2
17	9½	6½	2	6	4	4	10	6	7	10	4½	2½
18	12	8	2	2	4½	6	6½	7	5	13	4½	1½
19	11	8	4¾	¼	5	4	7	8	6	7	10	1
20	8¼	12	3¾	......	5½	5	9½	4	7	9	8	......
21	12	9¼	1	1¾	4	3	10	7	5	13	5	1
22	13	8	2	1	3½	6	8	6½	6	9	9	......
23	8½	10	3½	2	3	11	4	6	6	10	7	1
24	10	11¼	1¼	1½	4	9	7	4	5	12	7	......
25	12	10	1	1	4½	10	4½	5	6	14	3½	½
26	8	12	4	......	3	9	7	5	5	12	6½	½
27	11½	11¼	1¼	......	6	10	4	4	5	14	5	......
28	9	13	1	1	5½	10	5	3½	7	8	8	1
29	13½	8	½	2	3½	8	9	3½	6	8	8	2
30	9½	12	1½	1	4	9	7	4	5	10	8½	½
31	5	16	1	2	4	8	8	4	5	12	4½	2½
Feb. 1	6½	12	2½	3	3½	8	10	2½	6	5	11½	1½
2	10	10½	3½	......	......	......	......	......	8	10	6	......
3	......	......	......	......	......	......	......	......	6	6	12	......
Av....	9¾	10	2½	1¾	4½	7¾	7	4¾	6	9½	7½	1

[1]Gymnasium work at college, skating, wrestling, basket ball, hockey, running, teaching gymnastics, and coaching basket ball at High School; 20 mins. riding bicycle ergometer; "endurance test"; motion pictures.

[2]Work at Boys' Club, tending boiler and furnace, scrubbing floor, gymnasium work, basket ball, wrestling, skating, ice hockey; 30 mins. riding bicycle ergometer; "endurance test"; motion pictures.

[3]Gymnasium work, wrestling and skating; 30 mins. riding bicycle ergometer; "endurance test"; motion pictures.

was *Gul*, whose average figure shows but 4½ hours. *Gul*, throughout the entire period of observation, was referred to frequently by all members of the squad and by other men in the college as being the "hardest worked man in college." We may record here that no other man in the squad was observed to be more often dozing or nodding, when unemployed and sitting in a chair in the library at the Nutrition Laboratory and at other times. It would therefore appear as if the 4½ hours lying was a low estimate for the resting of this man. In consequence, the estimates for sitting and walking must be somewhat high. It is unnecessary to go into the individual figures to show how the different men vary from day to day, but only to say that the lying values are for the most part remarkably uniform, aside from those for *Gul*.

TABLE 194.—*Exercise records during reduced diet—Squad A*—continued.

Date.	Henry A. Moyer.				Allen S. Peabody.				R. Wallace Peckham.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]	Lying.	Sitting.	Walking.	Exercise greater than walking.[3]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 11	......	......	......	......	......	......	......	......	......	......	......	......
12	8	12	4	......	8	9	7	......	7	8	9	......
13	8	13	3	......	9	8	7	......	8	12	4	......
14	8½	9½	3½	2½	9	6½	6	2½	8	10	2	4
15	7½	10	4½	2	10½	3½	8½	1½	8	14	2	......
16	7	8½	4½	4	7½	4½	11	1	7	10	2	5
17	8	10½	4	1½	8½	6½	8	1	9	12	3	......
18	8	10	3½	2½	8½	4½	10	1	6	15	2	1
19	8½	5	5½	5	8½	3½	11	1	8	12	2	2
20	8	14	2	......	8½	3	12½	......	6	14	2	2
21	8	8½	4	3½	8½	5	10½	......	8	13	1	2
22	9	10	4	1	8½	6	9½	......	9	13	1	1
23	8	10¾	3	2¼	8½	6	7½	2	8	13	3	......
24	7	11½	4½	1	8½	6	8½	1	10	11½	2	½
25	9	10	3	2	8½	5	9½	1	9	13½	1	½
26	8	13	3	......	8	7½	8½	......	7	16	1	......
27	7½	14½	2	......	8½	7	8½	......	8	14	2	......
28	9	9½	3	2½	9½	5	8½	1	10	12	2	......
29	7½	9	6½	1	7½	6	9½	1	10	12	2	......
30	8	9½	5	1½	8	5½	9	1½	10	12	2	......
31	6½	10½	5	2	6½	6	10	1½	8	13	3	......
Feb. 1	7	10	4	3	6½	7	9	1½	8	12	2½	1½
2	......	......	......	......	5½	7	11½	......	9	13	2	......
Av....	8	10½	3¾	1¾	8¼	5¾	9	1	8¼	12½	2¼	1

[1]Chiefly janitor work; also gymnasium work, running, and swimming; 25 mins. riding bicycle ergometer; "endurance test"; motion pictures.

[2]Gymnasium work, wrestling, swimming; also ran 1½ miles; 25 mins. riding bicycle ergometer; "endurance test"; motion pictures.

[3]Chiefly hockey; also skating, gymnasium work, and shoveling snow; 30 mins. swimming, and 30 mins. running; 2 hrs. walking in low temperature; 25 mins. riding bicycle ergometer; "endurance test"; motion pictures.

Sitting.—With the striking exception of *Pea*, who reports an average of but 5¾ hours sitting, and *Gul*, who reports but 7¾ hours, the men in Squad A showed, on the average, a sitting value not far from 10 to 12 hours.

Walking.—The records for walking vary considerably; most of the men averaged not far from 3 to 4 hours. In striking contrast to this are, however, the values for *Gul* of 7 hours, *Mon* of 7½ hours, and *Pea* of 9 hours. Although every effort was made to secure as accurate and objective records for these men as possible, it is clear that errors—indeed, serious errors—crept into these estimates, for an examination of the pedometer records for Squad A from January 14 to February 2 shows that while the correlation between the number of hours estimated for walking and the miles recorded on the pedometer is reasonably constant with most of the men, we have several wide differences.

Thus *Gul* reported an average of 7 hours per day walking, while the pedometer showed but 10 miles. *Mon* reported 7½ hours with a mile-

TABLE 194.—*Exercise records during reduced diet—Squad A*—continued.

Date.	Leslie J. Tompkins.				Ronald T. Veal.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 12	....	....	....	....	10½	9	4½	....
13	....	....	....	....	8	12	4	....
14	8½	11½	4	....	8½	11½	2½	1½
15	14¼	9¾	¼	....	10	8½	5½	....
16	8½	11	4½	....	8	7	9	....
17	8½	10½	5	....	8½	11½	4	....
18	8	10¾	5¼	....	9	10½	3	1½
19	7	12	5	....	9½	9	5½	....
20	8	15	1	....	9	11½	3½	....
21	8	13	3	....	9½	9½	3½	1½
22	8½	13½	2	....	9	10½	2	2½
23	9	12½	2½	....	8	12	2½	1½
24	8	13	3	....	9	12	3	....
25	10	12	2	....	11	11	2	....
26	7½	13½	3	....	10	10	4	....
27	7½	15¾	¾	....	9	12	3	....
28	8½	13½	2	....	9½	11½	3	....
29	9	13½	1½	....	10	10	4	....
30	8	14	2	....	9	11	4	....
31	5	16¼	2¾	....	10	9½	4½	....
Feb. 1	10	8½	4	1½	9½	9	4	1½
2	6½	15½	2	....	6½	12	5½	....
Average	8½	12¾	2¾	0	9	10½	4	½

[1]A recent operation prevented Tom from engaging in strenuous exercise and called for a larger percentage of hours sitting. "Endurance test" and motion pictures on Feb. 1.

[2]Gymnasium work and snow-shoeing; 25 mins. riding bicycle ergometer; "endurance test"; motion pictures.

age of 5.8 miles. *Pea* with 9 hours, the highest record, showed a pedometer reading of but 6.2 miles. On the other hand, we have the extremely small value of 2.25 hours with *Pec*, and a pedometer record of 8.3 miles. Under the circumstances a strict comparison of either pedometer records or activity records must be made with great reserve.

Exercise greater than walking.—It is particularly unfortunate that we have to rely to so large an extent upon conjecture for this degree of activity. It is clear that in a number of instances the men reported under the head of walking quite a variety of activities which should have been reported as greater than walking, and *vice versa*. According to the records the exercise more strenuous than walking is for all the men somewhat light, *i. e.*, 1 to 2 hours on the average, although we have the excessive amount attributed to *Gul* of 4¾ hours. An admittedly unsatisfactory attempt is made to indicate in a general way the character of the exercise greater than walking; this is shown by the footnotes below the data for each subject. It can be seen that gym-

TABLE 195.—*Exercise records during reduced diet—Squad B.*

Date.	Edward M. Fisher.				Victor H. Hartshorn.				Karl Z. Howland.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]	Lying.	Sitting.	Walking.	Exercise greater than walking.[3]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 10	8	6	5	5	......	......	......	......	......	......	......	......
11	7	7	6	4	......	......	......	......	6	10	2½	5½
12	8	6	5	5	9½	4	8½	2	8	8	4	4
13	9	8	3	4	9½	7½	7	......	9	7	5	3
14	8	7	4	5	9	7½	5½	2	11	9	3	1
15	7	7	4	6	10	8	4	2	10	6	4	4
16	7	6	5	6	8½	8	4½	3	9	9	5	1
17	7	6	4	7	7½	8	6½	2	9	10	2½	2½
18	7	8	5	4	7½	9	6	1½	6	9	5½	3½
19	8	7	5	4	8	10	6	......	9	9	5	1
20	8	9	3	4	10	10	4	......	12	10	2	......
21	8	7	6	3	8½	9	6	½	11	10	2	1
22	8	7	5	4	9	11	4	......	10	9	3	2
23	7	7	6	4	8	11	3	2	9	11	4	......
24	8	7	5	4	7½	10	4½	2	9	9	4	2
25	7	5	6	6	8	10	6	......	7	9	5	3
26	7	4	6	7	11	11	2	......	8	8	7	1
27	8	6	7	3	9	10	5	......	7	12	5	......
28	......	......	......	......	8	10	6	......	8	10	5	1
29	......	......	......	......	7½	11½	5	......	......	......	......	......
Av....	7½	6¾	5	4¾	8½	9¼	5¼	1	8¾	9¼	4	2

[1]Chiefly gymnasium work and cleaning swimming pool; also swimming, skating, and dancing.
[2]Chiefly gymnasium work, also ice hockey, skating, scrubbing swimming pool, shoveling snow and running.
[3]Chiefly gymnasium work, basket ball, and skating; also running.

nasium work in various forms plays, as is to be expected, rather an important rôle. The work on the bicycle ergometer is not shown in the individual records but is given in the footnotes and taken account of in computing the average per day.

EXERCISE RECORDS FOR SQUAD B.

Squad B, having been put upon restricted diet on January 8, kept records of their activity similar to those of Squad A in the period from January 10 to 29, inclusive. An examination of the detailed figures, table 195, shows that in general the men were in bed about 8 hours a day. The hours recorded for sitting vary considerably for the different men, ranging from 6¾ to 12¾, but usually are not far from 9 to 10. The hours spent in walking are reasonably uniform, from 4 to 5 hours, while the exercise more strenuous than walking varies considerably, the majority of the men indicating not more than 1 or 2 hours. There is a striking exception in the case of *Fis* (4¾ hours).

TABLE 195.—*Exercise records during reduced diet—Squad B*—continued.

Date.	Robert L. Hammond.				Harold L. Kimball.				Robert H. Long.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]	Lying.	Sitting.	Walking.	Exercise greater than walking.[3]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 11	......	......	......	......	7½	10	3½	3	10	9	5	......
12	9	12	3	......	8	8	8	......	10	11	3	......
13	8	10	6	......	9½	8½	6	......	11	10	3	......
14	7	10	5½	1½	9	9	4½	1½	9½	8½	4	2
15	8	8	4	4	8	9	5½	1½	7	10	4	3
16	8	10	4	2	7½	9	6½	1	10	9	4	1
17	8	10	4	2	9	9	5¾	¼	9	10	3	2
18	10	12	1	1	9	12½	1	1½	9	10	3	2
19	9	9	6	......	9	13	2	......	8	14	2	......
20	8	10	4	2	8	10	6	......	8	12	4	......
21	9	9	4	2	8	9	6¾	¼	11½	5½	5	2
22	7	10	5	2	8½	9	5	1½	9	11	4	......
23	9	8	6	1	7	9	7¾	¼	10½	8½	5	......
24	8	6	6	4	7	9	8	......	9	7	6	2
25	8	7	5	4	8	9	5½	1½	10	7	5	2
26	9	10	5	......	8	9	5½	1½	11	4	7	2
27	10	9	3	2	6	9	9	......	9½	10½	4	......
28	8	10	2	4	8	9	7	......	......	......	......	......
Av....	8½	9½	4¼	1¾	8	9½	5¾	¾	9½	9¼	4¼	1

[1]Chiefly gymnasium work, shoveling snow, hockey, and skating; also wrestling, running, cleaning cellar and sifting ashes.

[2]Gymnasium work, swimming, and skating; also 5 mins. boxing and 30 mins. running.

[3]Entirely gymnastic exercise except 3 hrs. swimming.

TABLE 195.—*Exercise records with reduced diet—Squad B*—continued.

Date.	John Schrack.				Alfred Livingstone.				Chester D. Snell.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]	Lying.	Sitting.	Walking.	Exercise greater than walking.[3]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 12	9	8	7	......	......	......	......	......	9	10	4	1
13	9	11	4	......	......	......	......	......	9	7	7	1
14	9	9	4½	1½	9	10	3	2	8	10	6	......
15	8	12	3	1	11	8	3	2	7	13	4	......
16	8	9	6¾	½	9	10	4	1	7	14	3	......
17	8	10	4½	1½	10	9	3	2	7	13½	3½	......
18	8½	10	5¼	½	8½	11	3	1½	6¾	15	2¼	......
19	9	11	4	......	......	......	......	......	7	12	5	......
20	9	12	3	......	......	......	......	......	8	13	3	......
21	8½	11	4½	......	8	12	4	......	7	14	3	......
22	8½	10	4	1½	9	9	4	2	8	13	3	......
23	8	9½	6½	½	10	8	4	2	7	14	3	......
24	7½	11	4¼	1¼	9	9	4	2	7½	13	3½	......
25	7½	9	6¾	¾	9	8	4	3	7	14	3	......
26	8	7	3	6	9	8	5	2	7	13	4	......
27	7	9	8	......	......	......	......	......	8	11	5	......
Av....	8¼	9¾	5	1	9¼	9½	3¾	1¾	7½	12½	3¾	½

Date.	George H. Thompson.				Floyd M. Van Wagner.				Elton L. Williams.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[4]	Lying.	Sitting.	Walking.	Exercise greater than walking.[5]	Lying.	Sitting.	Walking.	Exercise greater than walking.[6]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 11	......	......	......	......	9	10	2½	2½	......	......	......	......
12	6	14	3	1	10	10	4	......	7	2	13	2
13	9	12	3	......	8	12	4	......	7	14	3	......
14	8	11	4	1	8½	10½	3	2	7	10	7	......
15	6	14	4	......	7½	8½	6	2	8	8	2	6
16	7	13	3	1	7½	11	4½	1	8	13	1	2
17	8	14	2	......	7½	10½	4½	1½	8	7	3	6
18	7	12	4	1	7½	10	5½	1	8	8	2	6
19	4	18	2	......	8	12	4	......	6	14	4	......
20	8	14	2	......	8	12	4	......	7	14	3	......
21	10	12	1	1	7½	11	4½	1	8	12	4	......
22	7	14	3	......	8	11	5	......	8	7	3	6
23	8	11	3	2	8	11½	3	1½	8	11	2	3
24	10	11	3	......	8	11½	3½	1	8	14	2	......
25	8	11	4	1	7½	12	3	1½	8	14	2	......
26	7	13	4	......	7½	11	3½	2	8	10	1	5
27	9	13	2	......	8	14	2	......	8	13	3	......
28	8	12	4	......	7	12	5	......	......	......	......	......
Av....	7¾	12¾	3	½	8	11	4	1	7½	10¾	3½	2¼

[1]Chiefly janitor work at Woods Hall (6 hrs.); gymnasium work and wrestling; also a little hockey, running, and skating.

[2]Chiefly swimming; also gymnasium work, hockey, wrestling, and basket ball.

[3]1 hr. basket ball and 1 hr. running. In calculating the average, included 15 mins. riding bicycle ergometer and 15 mins. exercise of climbing stairs not reported by Sne.

[4]Chiefly gymnasium work; also 1 hr. skating and 1 hr. hockey.

[5]Chiefly gymnasium work; also hockey, wrestling, and basket ball.

[6]Chiefly janitor work and basket ball; also hockey and athletics.

EXERCISE RECORDS FOR NORMAL SUBJECTS.

Since both Squads A and B were upon reduced diet, A at maintenance level, and B in a transitional stage, the primary object of this record of activity was to find the influence, if any, of the reduced diet upon the number of hours spent in the various activities other than sleeping and sitting. Since both squads were on diet, the values for a squad not undergoing dietetic restriction are of special interest. A group of volunteers kindly offered to make records for a corresponding time. The longest periods were from January 11 to February 3, but there was considerable irregularity in the length of the record. Nevertheless, for most of the group, the picture is probably not far from true. The results are recorded in table 196. The men were lying usually not far from 8 hours, the most pronounced exception being that of

TABLE 196.—*Exercise records of normal subjects during uncontrolled diet.*

Date.	Barckley.				Davis.				Edwards.				Erickson.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]	Lying.	Sitting.	Walking.	Exercise greater than walking.[3]	Lying.	Sitting.	Walking.	Exercise greater than walking.
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 12..	....	....	....	....	....	....	....	....	....	....	....	....	9	....	15	....
13..	....	....	....	....	....	....	....	....	....	....	....	....	11	4	9	....
14..	7	10	4	3	6	7	10	1	6½	6½	6	5	9	8	7	....
15..	7½	9	4½	3	7½	8	8½	....	6½	7½	4½	5½	9	8	7	....
16..	6½	10	4½	3	7	6	6	5	7	8	5	4	9	8	7	....
17..	8	10	4½	1½	6	6	9	3	5½	7	4	7½	9	8	7	....
18..	7	11	4	2	7	5	10	2	6	7	10	1	9	8	7	....
19..	9	5	8	2	8½	6	8	1½	6½	8	8½	1	9	....	15	....
20..	10	8	6	....	6	10	8	....	3½	13	4½	3	11	4	9	....
21..	7	6	7	4	11	6	5	2	7	6½	6½	4	9	8	7	....
22..	9	6	6	3	6½	8½	8	1	6½	6	8½	3	9	8	7	....
23..	7	6	6	5	7½	8	5½	3	5	7¾	11¼	....	9	8	7	....
24..	8	8	4	4	6½	6	9½	2	....	....	....	....	9	8	7	....
25..	8	8	6	2	6	8	7	3	....	....	....	....	9	8	7	....
26..	9	8	6	1	7	5	10	2	....	....	....	....	9	....	15	....
27..	9	8	7	....	9	8	7	....	....	....	....	....	11	4	9	....
28..	8	6	4	6	8	9	5	2	....	....	....	....	9	8	7	....
29..	7	7	4	6	....	....	....	....	....	....	....	....	9	8	7	....
30..	8	8	6	2	....	....	....	....	....	....	....	....	9	8	7	....
31..	7	7	9	1	....	....	....	....	....	....	....	....	9	8	7	....
Feb. 1..	....	....	....	....	....	....	....	....	....	....	....	....	9	8	7	....
2..	....	....	....	....	....	....	....	....	....	....	....	....	9	....	15	....
3..	....	....	....	....	....	....	....	....	....	....	....	....	11	4	9	....
Average..	8	7¾	5½	2¾	7¼	7¼	7¾	1¾	6	7	6¾	3½	9¼	6	8¾	....

[1]Chiefly gymnasium work; also skating, swimming, basket ball, running, hockey and dancing.
[2]Chiefly hockey; also gymnasium work at college, leading gymnasium classes in public school, and shoveling snow.
[3]Chiefly shoveling coal; also basket ball, ice hockey, leading drill and games at Boy Scout meetings; 2 hrs. moving chairs.

Table 196.—*Exercise records of normal subjects during uncontrolled diet*—continued.

Date.	Frank.				Grumman.				Hodge.				MacNeil.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]	Lying.	Sitting.	Walking.	Exercise greater than walking.[3]	Lying.	Sitting.	Walking.	Exercise greater than walking.[4]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 11..	....	....	....	....	8½	12½	1½	1½	....	....	....	....	....	....	....	....
12..	....	....	....	....	8	11	5	....	....	....	....	....	....	....	....	....
13..	....	....	....	....	8½	10½	4½	½	....	....	....	....	....	....	....	....
14..	....	....	....	....	7½	13½	1½	1½	....	....	....	....	....	....	....	....
15..	....	....	....	....	8	12½	2	1½	....	....	....	....	....	....	....	....
16..	9	11	13	1	8	12	2½	1½	7½	9	5½	2	....	....	....	....
17..	7	12½	4½	....	7½	13½	3	....	8	8	5	3	8	10½	4½	1
18..	6	12½	4	1½	8	12½	2	1½	7	6	8½	2½	8½	10½	3	2
19..	7	9	4	4	9	11	4	....	8½	10	4	1½	8½	2	2	11½
20..	10	11¼	2¾	....	9	11	4	....	6½	10	7½	....	11½	9½	3	....
21..	7	12½	3	1½	8	12½	1½	2	8	8	6	2	9	9	3	3
22..	6	14½	3½	....	8	13	2	1	11	8	4	1	11½	10½	1	1
23..	8½	11	3	1½	7	13	2½	1½	8	8	5	3	10½	7¾	5¾	....
24..	9	8	7	....	8	14	2	....	7½	9	5	2½	10	10	4	....
25..	7	12	5	....	7	13	4	....	6½	10½	4½	2½	10¾	10	3¼	....
26..	9	10½	4½	....	7	12	4	1	8½	6½	6	3	7¾	13	2	1¼
27..	6	15	3	....	9	11	4	....	9	10	5	....	....	....	....	....
28..	7	12½	3	1½	8½	12	1½	2	7½	9	5	2½	....	....	....	....
29..	7½	12½	4	....	8	14	2	....	8	9	5	2	....	....	....	....
30..	8	7	7½	1½	7	13½	2	1½	7½	8½	6	2	....	....	....	....
31..	6	12	6	....	6½	13½	4	....	8	9	5	2	....	....	....	....
Average..	7½	11½	4¼	¾	8	12½	2¾	¾	8	8½	5½	2	9½	9¼	3¼	2

[1]Entirely gymnasium work except 4 hrs. of snowshoeing.

[2]Chiefly gymnasium work and swimming, also hand ball, basket ball, dancing, club swinging and calisthenics.

[3]Chiefly hockey and gymnasium work; also shoveling snow, and swimming.

[4]11 hrs. sawing wood; also gymnasium work, wrestling, swimming, athletics, and basket ball.

Edwards, with but 6 hours lying. The time spent in sitting varied from 6 to 12½ hours, with very considerable irregularities and no modal value. The number of hours of walking was greatest with *Erickson*, 8¾ hours. This was probably due to the fact that his record includes 4 Sundays with 15 hours walking each, and no time for sitting. This is doubtless an exaggerated statement. On the other hand, *Davis*, who assisted in the pulse records and was thus used to making accurate reports, had an average of 7¾ hours per day of walking. The exercise more strenuous than walking, except for *Edwards* with 3½ hours, and *Barckley* with 2¾ hours, was not far from 1 to 1½ hours.

TABLE 196.—*Exercise records of normal subjects during uncontrolled diet*—continued.

Date.	Owl.				Ruettgers.				Stewart.			
	Lying.	Sitting.	Walking.	Exercise greater than walking.[1]	Lying.	Sitting.	Walking.	Exercise greater than walking.[2]	Lying.	Sitting.	Walking.	Exercise greater than walking.[3]
1918.	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*	*hrs.*
Jan. 14	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15	.....	.....	.....	.....	9	12	1½	1½	.....	.....	.....	.....
16	.....	.....	.....	.....	8	12	2¾	1¼	9	11	2½	1½
17	.....	.....	.....	.....	8	12	4	.....	9	10½	4½	.....
18	7½	11½	1½	3½	8	12	2¾	1¼	9	11	2½	1½
19	8½	9	4	2½	8	12	4	.....	9	13	2	.....
20	9	9	4½	1½	8	14	2	.....	8	13	3	.....
21	7½	12	2	2½	9	12	1	2	8½	11	3	1½
22	8	13	3	.....	8	13	3	.....	9	10	5	.....
23	7	12	2½	2½	8½	11	3½	1	9	11	2½	1½
24	8	13	1½	1½	8	13	3	.....	9	10½	4½	.....
25	9½	10	2½	2	9	12	2	1	9	11	2½	1½
26	7½	14	2½	.....	10	11	3	.....	9	13	2	.....
27	8½	12	3	½	10	8	6	.....	10	11	3	.....
28	8	11	2½	2½	8	12	2¾	1¼	8½	11	3	1½
29	6½	13½	3	1	9	13	2	.....	10	9	5	.....
30	9	12	3	.....	8½	11½	3	1	9	11	2½	1½
31	8½	10	4	1½	.....	.....	.....	.....	9	10	5	.....
Average	8	11½	3	1½	8½	12	2¾	¾	9	11	3¼	¾

[1]Chiefly gymnasium work, swimming, and running; also wrestling, basket ball, and skating.
[2]Chiefly gymnasium work; also skating and playing hand ball.
[3]Entirely gymnasium work.

COMPARISON OF THE ACTIVITIES OF SQUADS A AND B, AND THE NORMAL GROUP.

We have collected in table 197 the average values found with the various subjects in Squads A and B, and for the group of normal subjects, for the hours of walking and for the activity greater than walking, as these are the two factors that play the greatest rôle in indicating changes in physical activity. With both Squads A and B, the average time spent in walking was 4¼ hours, and with the normal subjects, 4¾ hours. For the activity greater than walking we find reasonable uniformity with all three squads, namely, 1¼ hours with Squad A, and 1½ hours for both Squad B and the normal group. The general picture of the data given in table 197 shows that the activities as measured by the time spent in walking or in exercise greater than walking were not strikingly different with any of the three groups. For Squad A the exercise more strenuous than walking is slightly lower by one-quarter hour per man per day, but the real significance, if any, of this small difference can not be determined.

It therefore seems from a study of the pedometer records and of the relatively small differences exhibited by the men in their records of

physical activity in tables 194 to 197, inclusive, that it is highly improbable that any large difference in the activity, either walking or exercise greater than walking, existed on the average with the three squads.

TABLE 197.—*Average exercise records of Squads A and B during reduced diet, and of normal subjects during uncontrolled diet.*

Squad A.	Walking.	Exercise greater than walking.	Squad B.	Walking.	Exercise greater than walking.	Normal. subjects.	Walking.	Exercise greater than walking.
	hrs.	*hrs.*		*hrs.*	*hrs.*		*hrs.*	*hrs.*
Bro......	3¼	1½	Fis......	5	4¾	Bar......	5½	2¾
Can......	3	½	Har......	5¼	1	Dav......	7¾	1¾
Kon......	2¼	¼	How.....	4	2	Edw.....	6¾	3½
Gar......	2½	1¾	Ham.....	4¼	1¾	Eri......	8¾	0
Gul......	7	4¾	Kim.....	5¾	¾	Fra......	4¼	¾
Mon.....	7½	1	Lon......	4¼	1	Gru......	2¾	¾
Moy.....	3¾	1¾	Sch......	5	1	Hod.....	5½	2
Pea......	9	1	Liv......	3¾	1¾	Mac.....	3¼	2
Pec......	2¼	1	Sne......	3¾	¼	Owl......	3	1½
Tom.....	2¾	[1]0	Tho.....	3	½	Rue.....	2¾	¾
Vea......	4	½	Van.....	4	1	Ste......	3¼	¾
....	....	....	Wil......	3½	2¼	....	....	....
Av....	4¼	1¼	Av....	4¼	1½	Av....	4¾	1½

[1]A recent operation for hemorrhoids prevented *Tom* from engaging in strenuous exercise and called for a larger percentage of hours sitting.

SUBJECTIVE IMPRESSIONS AS TO FITNESS FOR MUSCULAR WORK.

In the preceding paragraphs the records of general physical activity, as indicated by pedometer readings and other data, made as objective as conditions would permit, have been presented and analyzed. The men who were subjects in the experiment naturally had subjective impressions of their own readiness, ability, and performance in physical exercise. The members of Squad A had an extended period over which to observe themselves and each other. They were intelligent men and all unusually interested in physical exercise and bodily well-being. Seven of them were taking the physical director's course in the college. Their observations during and following the experiment, stated in essentially their own words, are as follows:

Bro.—November 10: "Enjoy physical work more than last year, no 'logy' feeling, more 'pep'[1] than last year." December 19: "I am walking more than usual lately." February 2: "There have been times in the experiment when I have felt weak in the knees, and seemed to get out of breath easily. The last ten days I have felt better than during the days just following the Christmas vacation." May 21: "The weakness in the knees in the experimental period was particularly noticed in stair-climbing. I found that I used the stair-rail more than usual when climbing stairs. I am sure the diet could not be recommended for soldiers. I have several times said that I should hate

[1]Colloquial abbreviation for "pepper," indicating vim or snap.

to see our soldiers put on that régime. Under the conditions of an athletic contest, two teams may go through substantially the same motions and the same team plays, but one team does it with more snap and gets there quicker; that team is going to win the game. It was just that added snap that the men on the reduced diet lacked, and which would be the essential thing that a soldier must have in order to succeed."

Can.—November 10: "Requires more effort to climb stairs, to go out for a walk, and similar activity. One has to use more will power to accomplish the same things. One tires more easily. On one occasion, I felt exhausted after playing soccer in which I walked about 16 miles in all." November 24: "Heavy gymnasium work yesterday and got very tired." January 12: "Since vacation I have felt the same as at the beginning of the experiment, generally tired, with feelings of weakness." January 26: "One day I may feel good, the next have a great lack of 'pep'." February 2: "To-night I feel pretty 'rotten' as a result of yesterday's endurance test." February 8: "There is no weakness now and I have much more 'pep'. I have not been lying down at noon time as I did during the experiment to save myself." May 22: "In general, lack of endurance was manifested in athletics in my case. Think I could not have kept up the low diet much longer. I believe that if the military were on the same régime, the efficiency of the individual soldier would be decreased." During the experiment he adopted the method of hurrying up and down stairs to get it over with on account of the uncomfortable feelings in the knees and thighs.

Kon.—November 10: "The staying power has not been very great; have noticed absence of 'pep'. Feel weak in the afternoon when running with football." February 8: "Have done but very little physical work since close of experiment and therefore can not make a good comparison; feel stronger."

Gar.—November 10: "Physical power very much less than that before low diet, less endurance; tire easier if I walk any distance; weakness in legs felt when I go upstairs; very tired after teaching 6 gymnasium classes on alternate days at the high school." December 8: "Feel good physically." January 12: "Felt weaker this morning than at any time while on the squad." February 8: "No improvement in physical work noted as yet; I have not done any gymnasium bar work so far. The first day or so after the experiment I was very sleepy."

Gul.—November 10: "Felt normal until the last two or three days, when I experienced weakness, and lack of 'pep'. Somewhat more tired after the boys' club work at night than before, but overcrowded with work." November 24: "A little tiredness in legs develops in the evening, otherwise all right. Worked at writing all last night." December 19: $3\frac{1}{2}$ hours sleep last night; usually take $4\frac{1}{2}$ to 5 hours sleep. I do not have time for more." January 12: "Feel a little faint. It commences to be pretty much of a drain; notice it physically more than before vacation." January 19: "Subject, fasting, completely chinned himself 12 or 13 times in the laboratory." January 26: "Felt good all the week." February 8: "Physical work is below par. Could not do certain exercises in gymnasium. Think it is because I am eating so much."

Mon.—November 10: "Feel weak from hunger; no weakness in the walking upstairs; weakness when running or in football; haven't the 'pep' that I had before, but would not hesitate to scrap with a friend." November 24: "Not so much 'pep' as before the reduced diet." December 8: "Weakness

is not localized in the legs, but is general." January 12: The experimenter said, "Well, you feel bully to-night, don't you?" Reply "No! not bully by a long ways. I am weak, weaker than before vacation, or I notice it more. I returned to college at my prescribed weight." February 8: "There is no weakness now. I can do my physical work better."

Moy.—November 10: "Doing the same amount of work as usual, but have felt more tired after it." November 24: "Perfectly normal, only that in going upstairs, legs are decidedly weak." December 8: "Feel normal in every way." January 12: "I have no 'pep' at all; can hardly drag around; felt all right just after I came back from vacation." At no time during the first part of the experiment did he feel the weakness so much as in the reduction period following vacation. February 2: "In general, there was considerable weakness during those periods when the weight was actively being reduced. At other times there was not nearly as much difficulty." February 8: "No feeling of weakness now. In gymnasium work the past few days, I felt 'logy' and sleepy from overeating. Now, when lying or standing, I notice the difference in breathing; seem to breathe deeper, and not so many short breaths as when on diet." May 21: "Notice definite difference between physical condition now and when I was on diet. To-day I was swimming in the lake; after the swim I ran up the hill, a rise of 50 or 60 feet, and then on up to the top floor in the dormitory, which meant climbing three flights of stairs. Upon reaching the top floor, I was of course out of breath, but I had none of the feelings of weakness which I previously reported as characteristic of the diet period. At times during the experiment in going upstairs I felt like putting my hands on my knees and pushing with each step to help myself up, particularly when I went slowly. When on the experiment if the diet squad men had hard gymnasium work, such as iron dumb-bells and iron wands, before the exercises were over, they began to slow up and felt fatigued. They simply could not push out the weights, and would skip a few counts. After the period of uncontrolled diet, the conditions were very different. Men were able to do these things without feeling the same fatigue as before. The change was also marked in my case in swimming. I think men on a diet such as we had would not make very good soldiers. They certainly would not feel like going 'over the top'."

Pea.—October 27: Not tired from the 5-mile run this morning. November 10: Legs somewhat weak in the cross-country race this morning. At times, does not feel able to do cross-country work. Muscles of legs have pained him some lately. November 24: Finds that he is weak on the indoor gymnasium work. Until now he has only been doing running this year; recently on one evening he boxed 20 minutes, wrestled for 20 minutes, ran a 2-mile race in 10 minutes, and felt very good afterwards. "With me the more exercise the better, but I feel the weakness in the legs reported by the other men." December 8: Still has weakness in the legs. December 12: "This morning is the first time in two months that I have been able to run up all the flights of steps to the fourth floor two steps at a time. I feel fine." December 19: Physically never felt better than during last 10 days; not bothered about going upstairs now. In gymnasium apparatus work, however, he has no strength in his arms. No desire for diving and swimming, as he usually has. January 26: During last fortnight has not felt nearly as well as before Christmas. Tired and weak most of time, having the same amount of exercise as before Christmas. He cannot perspire with any kind of exercise now. February 2: "In the cross-country running in the fall I noticed hardly any change, except in lack of ability to sprint at the end of the race.

With gymnasium work in general I noticed particularly weakness in the wrists, ankles, and in the other joints under conditions of suspension." May 22: Recalled his feelings of weakness in the knees, ankles, and wrists associated with the experiment. Spoke of the pleasure he experienced at being able to run up all the stairs to the respiration laboratory in the dormitory before the Christmas vacation without the subjective sensation of weakness. "One can run upstairs on his nerve even though he has the weakness, but there were times, I believe, when I could not possibly run up more than one flight of steps." The subject differentiated sharply between those periods in the experiment when the weight was actively reduced, as in October, November, and January, and the long period of weight maintenance in December. "During the period of reduction, one is physically uncomfortable, ineffective, and hungry all the time." In his own case he frequently had to go to bed early in the evening to forget his unpleasant feelings. "Concerning the cross-country races, I was beaten in the two intercollegiate events, once by a Wesleyan man whom I beat last year. In both races the representative from the other team and myself led the race. We ran well together until we came near the end. As we left the swamp about a quarter of a mile from the finish and started up the long grade, the other fellow simply went away from me in spite of all that I could do. I seemed to have plenty of endurance, but I could not sprint as normally for the finish. Following the race I was in much better physical condition than the other runners. They were exhausted and nearly at the point of physical collapse, while I felt fine and could have run again. In reference to the gymnasium work, as I have stated, I always noticed the lack of strength in my wrists and arms to do the apparatus work."

Pec.—November 10: Notices a loss of "pep" and staying power (endurance); all right after he once gets started; notices weakness in climbing stairs. Had to work hard to reduce and thought this made him weak. January 12: "Feel stronger and more comfortable than before Christmas. I am playing hockey as goal tender now." January 26: "During last few days I ran down in vitality but not in weight." February 2: "I have felt rather better than usual physically during the week; continually improving since early days of experiment." February 8: Hockey game was lost by a heavy score. Thought to have been due to the subject's weakened physical condition.

Spe.—November 10: Feels weak tonight, particularly in going upstairs. When he rises suddenly, everything turns black. After work in the afternoon, if he walks up three flights of stairs to respiration laboratory he is more tired than usual. He has as much "pep" as before diet. November 24: Has not the endurance for physical work that he formerly had. A swim of two full lengths of the pool makes him tired; not so usually. Weakness in the legs is conspicuous. May 22: "I think it is quite logical for a man to say that he is weak in the knees, and later be seen to run up and down stairs. I remember clearly that I used the stair rail more when going up and down stairs and bore part of my weight with the hands. In the fall term I did practically as well as usual in class football team practice against the university team as I would have done under normal conditions. I think, however, that in the winter term my athletic work was not up to standard."

Tom.—November 10: "Was up late last night and had only 4 hours' sleep. Tearing around Boston this afternoon and am sleepy now, but otherwise I feel good." November 24: "I feel fine, but cannot get thinner. I have not the time to work off flesh the way the other fellows do." December 19: "Feelings of weakness are not prominent in my case." January 26: "I am

not recovering from my operation as I should and my physical condition is poor." February 8: Has more "pep" and strength than at the close of the diet period.

Vea.—October 27: "Played tennis all the morning. I am feeling all right." November 10: Feels about the same, except legs get a little more tired than usual. Has been doing more work than usual in order to reduce. "If I could eat food that would go to my legs I would feel all right. My legs are weak. I notice it particularly when walking upstairs. It can not be because of an over-amount of exercise." November 24: Past week much tiredness in legs. January 12: Noticed a little tiredness in the legs. January 26: "This week I have been tired all the time. I do not know why." May 21: "The sensation of weakness in the legs was not so prominent when I was running. It is all gone now."

Certain members of the faculty were especially competent to pass judgment upon the physical fitness and performance of the men. They were continually observing them in their gymnasium and other athletic activities. These instructors discussed the matter with us very frankly. The individual interviews were on May 21, 1918. We are greatly indebted to these gentlemen for the privilege of including their statements which have been made from as nearly as possible an unbiased point of view. They were all heartily in favor of having the experiment carried out at the college and aided us in every way possible.

Professor George B. Affleck said: "The physical endurance of the men was not up to normal when they were on the diet. For one thing, they would ask for the privilege of wearing their sweaters during the exercises in athletics, and whenever possible they would seek to be near the radiators. Then, in the athletic work, some of them tried to play hockey, others to engage in the swimming and other athletic sports. Their endurance was less than in previous years and also was less than that of their fellows. It is impossible to say whether this was because they were physically unable to do the task or were lacking in desire. It may have been partly mental attitude although they seemed to want to do it and keep up with the others. I think in general it might be said that the men on the diet were more passive. They did not seem to feel so strongly. They certainly did not persevere in an athletic contest as one would think they should. They did not have the fighting spirit nor the determination to win. They were not so boisterous and overflowing in spirits as the other students or as themselves before and after the diet."

Mention was made that the men complained of weakness in the legs, and yet at times were seen to be running up and down stairs as occasion or interest prompted. Professor Affleck commented as follows:

"Yes, they complained to me a good deal about the weakness at times in stair-climbing. I think it quite compatible that a man should thus complain and yet be seen to run up or down stairs. This running is largely a habit. Then, too, there is a good explanation, although it may not have been thought of by some of the men. It takes a certain amount of time for the troublesome and more or less unpleasant sensations connected with weakness in stair-climbing to come to the foreground, just as it takes time for certain

fatigue effects to develop. It is possible that one may by running so shorten the process as to avoid, in part at least, the unpleasant sensations."

Professor Affleck felt secure in the conviction that the men on low diet would not make good soldiers. He said:

"They did not have the proper spirit of 'punch' for fight. It was often noted that they were tired, lax, and not so alert as usual, unless they urged themselves especially to the effort."

Professor Austin G. Johnson, as explained on page 396, studied the men while they rode the bicycle ergometer. Concerning the work which the men performed, he made the following general statement:

"Very frequently after a man on low diet had finished riding on the bicycle ergometer, and was lying on the plinth, he would say 'I should like to stay right here for two hours,' or would make some other remark, or by action show the fact that he was fatigued. Such remarks and indications were more frequent and pronounced with the men in Squad A than with the members of Squad B."

Professor Johnson made an interesting observation concerning the matter of perspiration during and following the ergometer work.

"During the low-diet period, the men in Squad A perspired only slightly during the exercise of riding while the Squad B men on full diet perspired very freely, in great contrast to the low-diet men. After the end of the experiment with Squad A (February 3), they did not ride on the ergometer again until February 8. In the meantime their weight had increased considerably and the difference in perspiration was astonishing. *Gul* perspired fearfully upon this latter occasion and panted in a striking and unusual way. Others of the men were noted to perspire very freely in contrast to their former condition, and they appeared to be much out of breath following the work."

Professor Elmer Berry had the following statements to make:

"I am glad that you have not recommended for the military and for men doing hard muscular work a dietetic régime such as that involving the degree of reduction in food in these experiments. Certain of the men of Squad A regularly had what would be regarded as hard, muscular work in athletics; Peabody, for example, and Gardner, also Kontner, who played football a good part of the season. In general most of the men were doing the usual amount of athletic work. While it is true that Peabody and Gardner carried on their heavy physical work, the former doing particularly well in his cross-country races, yet it is my impression that the men generally were definitely below par in their performance. My impression of the men in the gymnasium, for instance, is that they did not seem to be physically fit to do some of the heavier apparatus work. To be sure, this condition may not be entirely due to the diet as the circumstance of less sleep and the many details in connection with the experiment which drew upon the energies of the men were no doubt contributing factors. The feeling of cold was particularly prominent and the men had to be relieved from some of the swimming work on account of the complaints of severe cold. In reality the water in the natatorium was rather warm and no complaints were made by the other men. I think there may have been a slight disinclination for quite so much work in the gymnasium. In general, as a conditioner of men and as an athletic coach I have

these very definite opinions in regard to this diet and its relation to the fitness of men for athletic performance."

Professor Louis C. Schroeder had immediate charge of the gymnasium work of the men. On the occasion when he came to interview one of the authors, he stated that he had some definite ideas about the men and their physical condition during the diet experiment. These he gave without being questioned.

"The program in gymnasium work consists of an hour and a half each day for 5 days of the week. They spend about 7 minutes in marching, 20 minutes in vigorous calisthenics, 30 minutes in apparatus work, 20 minutes in gymnastic dancing, and about 10 minutes in a game. In the calisthenic work the men simply did not have the endurance; they would work quite well for about 5 minutes and after that could not keep up with the other men in the class. With the apparatus work they did not have the strength to do what is here (at Springfield) considered the ordinary senior apparatus work; strength was lacking. What was true of the calisthenic work was also true of the gymnastic dancing, which was more vigorous than the calisthenics.

In the apparatus exercises on parallel bars, in which there was considerable support work, as, for example, in doing shoulder stand, the men on diet did not have the motor control or the strength that was demonstrated by the others or had been previously shown by themselves; they did not come up to expectations. I am not saying they would make a poor showing in all gymnastics and athletic work. In our calisthenics here at Springfield the efforts demanded are what you might call of an explosive type—quick and intense; they do not require the same qualities, perhaps, as the running of a long distance race, but might be better likened to the sprint at the finish. Any particular explosive calisthenic exercise might be repeated 20 or 30 times successively and in this sense, they test endurance."

When asked about the application of such a dietetic régime to the life of the soldier Professor Schroeder said:

"In long rhythmic marching, when the men would gradually work into it, I have no way of judging whether the individuals on such a diet could stand up to the game with their fellows or would be better or poorer. But in circumstances requiring intense, extreme exertion, the gymnasium experience would indicate that this sort of a food reduction, at least in the degree here employed, would place the soldier in a very precarious condition."

Professor Schroeder made the following comments concerning Peabody, who served as his assistant during the winter and conducted the army work class in calisthenics and games 1 hour per day:

"The standing of the cross-country teams with which we contested this year can not be stated surely. I do not know if they were better, poorer, or of average ability. Considering the large number of college men who are now in Government service, some might assume that the teams would not be up to standard. Nevertheless, we were all enthusiastic over the remarkable physical ability and endurance which Peabody showed in these races. In the gymnasium, however, he was not able to perform up to his standard on the apparatus. In the rapid calisthenics he showed more energy and endurance than any other man in Squad A.; there is no question about it. I am not ready to admit that he did as well as usual."

Concerning the particular matter of weakness in the knees and in stair-climbing, Professor Schroeder made this comment:

"The men frequently mentioned weakness in the legs, and you will observe, or at least it seems to me, that stair-climbing calls for just that type of intermittent, intensive exertion used in the calisthenics and gymnasium work which I have described.

"No tests in the nature of quantitative endurance or strength tests were applied in the college gymnasium during the period of the experiment, and no effort was made to play the men on low diet against others for the purpose of seeing what they could do."

Comments concerning physical condition and performance might have been multiplied almost endlessly. The subjects were not encouraged to discuss at length conditions and impressions of this nature until at the end and after the experiment, for we recognized fully that subjective impressions of one's physical activity are often very misleading and inaccurate, particularly in judging the fineness and adequacy of muscular performance. The feeling of ease and success is, however, a most important matter. Any alteration in dietetic habits naturally tends to make an individual more or less introspective. Perhaps the majority of the men when they began the experiment had the general notion that they ate too much. It is only surmised that on this basis some might expect to be more efficient on the reduced diet. On the other hand, one of the most competent subjects remarked in an interview: "I think that during the diet we were rather 'scouting for trouble'." There is no doubt but that among themselves the men frequently discussed and compared notes on their individual conditions. Under the circumstances, with the men living together and eating at the same table, this could not well be avoided.

Notwithstanding these limiting conditions, which are of course not peculiar to this experiment alone and which make it impossible to evaluate accurately their subjective evidence, the comments from both men and instructors are so uniform and there are so few clear contradictions that the following conclusions regarding physical condition and activity seem tenable. Associated with the prolonged period of reduced diet the individuals studied frequently experienced:

(1) Feelings of general weakness and tiredness, a condition commonly expressed in college slang as lack of "pep" or drive, when it seemed to require more energy to accomplish a given amount of work and it was necessary to urge oneself harder.

(2) Weakness of the legs and accompanying unpleasant sensations of fatigue, particularly in stair-climbing.[1]

[1]Concerning the prominence of statements about weakness and fatigue in stair-climbing, there is one circumstance in the arrangement of the experiment which is of considerable importance. The respiration laboratory was located on the fourth floor. Here also arrangements were made for the collection of urine and feces. This rather unfortunate location necessitated for many of the men that they make a trip up and down three flights of stairs for every urination and many defecations, for all the Springfield experiments, to see notices posted on the laboratory bulletin board, make appointments, etc. This probably increased the necessary amount of stair-climbing during the months of the low-diet experiment.

(3) Subnormal gymnasium and athletic performance, as shown by inability to continue the rapid calisthenics or to do the heavy apparatus work for the prescribed time and with the usual subjective satisfaction, and generally to produce effectively sudden bursts of energy.

These feelings or experiences were not homogeneously distributed throughout the whole period of 4 months, during which the reduced-diet experiment lasted. The adverse criticisms apply for the most part to the periods of low diet intake, *i. e.*, during the periods of transition. During the 2 or 3 weeks prior to the Christmas vacation, a period we have selected as one of our maintenance periods, and again during a similar maintenance period near the end of the experiment, unfavorable comments were rare. The men said that they could get on indefinitely at that level and that their working ability was sensibly normal.

PHYSICAL CONDITION AND ENDURANCE TESTS.

A permanent record of the physical condition of Squad A was made on February 1 by a series of motion pictures. After a few weeks or months the personal impression of the appearance or action of a group of men becomes very indefinite, but a motion picture gives a permanent record of the exact occurrences and condition at the time of taking the picture. In all the pictures it was arranged that one of us should indicate the speed of action by swinging an Indian club to the beat of a metronome timed in seconds. Thus on the projection of the pictures one could see instantly whether the movement was abnormally rapid or abnormally slow. By timing the reproduction to correspond to the movement of the Indian club, the actual time of the movements of the subjects could be determined. This method of recording the rhythm of movement has been very successful, although special projection conditions are necessary. These motion pictures showed the men (1) in four typical gymnastic exercises, (2) "chinning the bar," and (3) diving from a springboard. After the men had dressed and eaten dinner, they returned to the gymnasium for an arm-holding contest to determine their physical endurance.

For the motion pictures in the morning, the men put on black swimming jockey straps and assembled in the gymnasium under the leadership of Mr. Greyson C. Gardner (*Gar*), who had been teaching gymnastics in the Springfield high school during the winter. The four typical gymnastic exercises involved considerable muscular activity. Possibly the most fatiguing and the longest continued was that designated in gymnasium parlance as "arm flexions with stride jumps." The men went through this exercise at a very rapid tempo, accomplishing 17 jumps in 18 seconds. Two sections of film were made for these four exercises, the second section showing an exact duplicate of the series of exercises performed for the first section of film. After the test for "chinning the bar," which will be discussed in detail later,

the subjects went to the natatorium and first dived in succession from the springboard, then at a signal dived together into the water. Undoubtedly the men were somewhat stimulated in these tests by their novelty. They certainly showed vim and spirit which seemed almost impossible with a group of men who had been on a restricted diet for so long a time. It has been the consensus of opinion of the many scientists who have seen the projection of these films that the men neither looked nor reacted as if underfed.

After a long period of extremely low diet it is necessary to know the effect upon not only the metabolism, pulse-rate, blood pressure, and other measurable physiological factors, but to secure, so far as possible, relevant evidence regarding endurance. Much of this evidence must depend upon introspection and upon the comments of the associates of the men in college. Such evidence has already been commented upon *in extenso*. Although the neuro-muscular tests reported earlier gave information as to the capacity for work under special conditions, and the pedometer records and personal activity records of the men also provided a reasonably accurate index of the total activities of the day, further direct evidence regarding the endurance and the capacity of these men for more or less prolonged effort seemed desirable.

Certain information as to the physical endurance of the men in Squad A at the end of 4 months of low diet was secured in the motion

TABLE 198.—*Results of "chinning the bar" test, Feb. 1, 1918—Squad A.*

Subject.	Time suspended on bar.	Number of "pull-ups."	Best previous record and date.
	Secs.		
Bro......	52	12	12 (1916).
Can......	42	5	Feb. 1, 1918, probably best record.
Kon......	52	12	Never tried before.
Gar......	57	22	Probably as good a record as ever.
Gul......	40	14	24 (1913).
Mon......	71	13	
Moy......	37	8	12 (1917).
Pea......	74	15	18 (1916).
Pec......	37	5	5–10.
Tom......	26	7	12 (1917).
Vea......	34	5	15 (1915).
Av....	....	11	....

pictures of the "chinning the bar" tests. In these, the 11 men were lined up along a bar about 8 feet from the ground and at a signal were required to jump to the bar, catch it, and chin themselves as many times as they could. They were allowed to choose their own tempo in this exercise. The exact time that the men hung on the bar was subsequently obtained by running off the film and using the metronome beats to determine the time in seconds. The number of pull-ups was

counted for each man, who also made a statement as to his previous best record. Table 198 shows the number of pull-ups for each man, the length of time that the men were hanging on the bar, and the previous best performance of the men. The men thus exercised the arm muscles practically to the limit of endurance.

The length of time suspended on the bar is of itself a test of endurance, and possibly we should have timed this alone without the chinning.[1] The average number of pull-ups (11) is certainly not a discreditable performance for the whole squad, although the competitive element was in part lacking. Each man was supposed to do his best, but as some men were recognized as trained athletes and others were not, keen competition hardly entered into the performance, save, perhaps in the case of *Mon* and *Pea*, who remained suspended a much longer time than the others.

With reference to the best previous performance, *Vea* showed a falling off of two-thirds. That this is a fair criterion hardly seems possible, as the best previous performance was undoubtedly preceded by special or general athletic training for the contest. It is not without significance that the best performance of the squad was made by *Gar*, who reports the record of 22 as probably his best.

The "chinning-the-bar" test, while strongly indicative of endurance capacity, can hardly be suggested as an endurance test capable of general use and particularly for comparison purposes.

A satisfactory test for endurance that meets the requirements of all critics does not as yet exist. In his study of the effect of excessive mastication of food,[2] Professor Fisher, of New Haven, made an extensive series of experiments in which he employed certain simple tests designed to show the degree of endurance.

Among other tests of endurance, Professor Fisher employed that of holding the arms horizontally at the level of the shoulders, with palms of hands down, and reported the results obtained with a group of flesh-eaters and a second group of flesh-abstainers. One of us, P. R., was a member of the second group of subjects. It seemed desirable to apply essentially this type of endurance test to the members of Squad A. Professor Fisher kindly wrote us at length regarding the conditions that should be met in a test of this kind, and due consideration was given his suggestions. The final plan was to have the men hold the arms, palms down, at the level of the shoulders, but pointing forward at an angle of about 45°, the idea being that if they were held directly out from the body and in opposite directions the head would have to be turned from side to side to see that the arms were being held in position; if they were extended directly in front, the arms

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[1] Marsh, Psychol. Rev., 1916, **23**, p. 437.

[2] Fisher, Yale Med. Journ., 1907, **13**, p. 205; also Trans. Conn. Acad. Arts and Sciences, 1907, **13**, p. 376.

would hamper respiration. If they were extended in front, at an angle of 45°, they would be easily visible, and otherwise the position would be more comfortable than the first two mentioned.

This form of test was considerably criticized in our discussion previous to its use, and it is only fair to state that as finally employed it did not meet the full approval of any of us, and was particularly criticized by P. R. who had participated in the earlier test. The members of Squad A were favorable to engaging in this competition test. It was not forced upon them.

On February 1, 11 members of Squad A were assembled in the gymnasium; pitted against them were 11 men selected from the college body. None of these latter were taken from Squad B, as Squad B had been on restricted diet and was in the realimentation period. The men were arranged in the form of an elongated horseshoe, with Squad A on one side and the volunteer squad on the other. At a given signal the subjects were told to extend the arms and hold them in the prescribed position. No talking was permitted, and although there were a number of spectators in the gallery, all were cautioned to make no comments, and to refrain from expressing appreciation or disapprobation in any way. We believe from this standpoint the test was successful. Two of us were present and one walked up and down behind either squad, cautioning the men to keep the arms from wavering and not to lower them unduly.

TABLE 199.—*Results of endurance test.*

[Duration, 1 hour; $2^h 28^m$ p. m. to $3^h 28^m$ p. m.]

Subject (Squad A).	Endurance.		Subject (controls).	Endurance.
	min.	*sec.*		*min.*
Tom....	18	30	1.......	14
Kon.....	21	20	2.......	27
Can.....	37	0	3.......	44
Pec.....	56	30	4.......	60
Bro.....	60	0	5.......	60
Gar.....	60	0	6.......	60
Gul.....	60	0	7.......	60
Mon....	60	0	8.......	60
Moy....	60	0	9.......	60
Pea.....	60	0	10.......	60
Vea.....	60	0	11.......	60

The experiment began at $2^h 28^m$ p. m. The period of endurance for each man is given in table 199, the members of the control squad being designated by numbers. The experiment was concluded at the end of 1 hour, as other plans had been made. Furthermore, from the previous experience of Professor Fisher, it was deemed hardly probable that any number of the men in either squad could hold out their arms as long as this. Indeed, if we examine Professor Fisher's records, we find that of 15 flesh-eaters tested, the longest period the arms were held out was 22 minutes; the average of all was 10 minutes. Of the 32 flesh-abstainers, 9 men held out the arms longer than 1 hour. The average for the flesh-abstainer athletes was 39 minutes and the average for the sedentary flesh-abstainers was 64 minutes. It is important

to point out that in our test flesh-abstainers did not enter, as both the men in Squad A and those in the competing squad were flesh-eaters.

Whatever opinion one may have as to this test being a true measure of endurance, and obviously with the variance between the data secured by Professor Fisher and by us in our experiment, the test is open to great criticism, it is clear that the members of Squad A as a whole made equally as good a record as the competing control squad. Such tests are at best so uncertain that a strict comparison may not properly be made between the observations of Professor Fisher and our own. It was believed by the spectators that the men in Squad A were more frequently cautioned and kept to the mark more rigidly than the members of the volunteer squad, inasmuch as the arms were extended without appreciable lowering more accurately and more consistently. There was much alternate sagging and raising of arms, however, with both squads. To the observer it would appear as if both squads met identically the same conditions. We have here, if not an actual test of endurance, certainly a test of comparative endurance between a squad on restricted diet and a squad on ordinary diet.

Emphasis should be laid upon the fact that owing to the coal-conservation measures in force at that time, the gymnasium was extremely cold. Most of the spectators and some of the assistants wore overcoats and hats, while the competitors wore ordinary indoor clothing or light sweaters and no hats. Many of the members of Squad A complained of cold hands, and the experimenters observed that the hands of these men were distinctly blue with the cold. Furthermore, Squad A had been through a rather drastic athletic program, including two series of gymnastic exercises, diving, and particularly the exhausting "chinning-the-bar" tests in the morning about $1\frac{1}{2}$ or 2 hours before this endurance test took place. The element of competition also entered into the endurance test, for each member of Squad A was determined to outlast his opponent on the volunteer squad. Probably this stimulus did not obtain as strongly with the volunteer squad, for they had relatively little to gain by a prolonged test, although naturally they did not want to be defeated by their supposedly undernourished competitors.

The only interpretation permissible from this endurance test is that the members of Squad A, after living 4 months on a considerably reduced diet, showed an endurance, as measured by even this imperfect test, equally as good as that of 11 men selected from the college body who were living on full diet.

GENERAL CONCLUSIONS REGARDING PHYSICAL ACTIVITY AND ENDURANCE.

From the four main indices of capacity for physical performance, namely, pedometer records, activity records, subjective impressions, and endurance test, the first two and the last have demonstrated no material difference between Squad A and groups of students living on

uncontrolled diet. The unfavorable subjective impressions are applicable more particularly to the transitional periods and bear with very much less force upon the period of maintenance. The prime object of this study is to note the capacity for physical exercise of a squad of men whose body-weight has been materially reduced by previous dietetic restriction and who are subsequently given calories for maintenance. Our evidence, more particularly the subjective impressions, clearly indicates that during the periods of low energy intake, *i. e.*, transition periods, the capacity for effective work was materially lowered. That there was not a pronounced indication of a lowering both in the pedometer records and in the activity records is surprising. All four indices of capacity for physical exercise are concordant in showing that at the periods of weight maintenance the members of Squad A, who were not a selected group of prime athletes, lived normal lives, and performed as much physical exercise as was carried out by their colleagues who were not on reduced diet.

MENTAL ATTITUDE AND SCHOLASTIC WORK.

The food reduction used for Squad A in this investigation may be regarded as a major change in the diet of these men. This reduction was continued for a relatively long time; the men lost approximately 10 per cent in weight and in general lived at this lowered level for about 2 months; certain striking physiological changes resulted. The introspection and comments concerning the diet and physical activity have been presented. From the mental side, also, certain general questions suggest themselves; (1) What was the character of the psychological environment for this experiment? (2) What in general was the mental attitude and disposition of the men during the experimental period? (3) As college students, how did the men of Squad A progress in their studies during the months when they were on reduced rations?

Regarding the first two queries, we have only the comments of the men themselves and of their instructors and other associates. Concerning the scholastic work there is the added evidence of term grades given in the different courses and under the different instructors. It is difficult in the introspection and personal impression material to make a clear separation between that which relates to physical condition and performance on the one side, and mental ability, disposition, and attitude on the other. In fact, no inflexible boundaries can be set. For purposes of analysis, however, we may look at personal comment from the two points of view. In the following notes we have entered those things which seem to relate particularly to the psychological or mental side. There is a very minor amount of duplication between these notes and those given under the heading of physical activity:

INTROSPECTIVE COMMENTS OF SUBJECTS.

Mon.—November 10: Feels only fair; too weak; can not concentrate attention. December 8: "I am weak and irritable." January 26: "For the past few days I have had to go to bed early in the evening and study in the morning; I have noticed the weakness more since Christmas." At the end of the patellar-reflex measurements the subject was found to be asleep. February 2: "The chief difficulty with the whole experiment has been the sensation of being continually weak. I think this has not affected my physical work quite so much as it has my studying. I have noticed repeatedly that I could not seem to concentrate my attention on this sort of work." Subject reports himself to have been by habit a very heavy eater before the experiment. February 8:[1] "Can study better now."

Tom.—November 10: Thinks he is keener and can do mental work easier since the experiment began. December 8: He is annoyed because the other fellows urge him to take more physical work and reduce faster; says he has not time to do it. "It makes a difference if one comes first in the evening in the individual psychological experiment as to how you feel for sleepiness; I notice the difference between now and the previous session. This is the first time that I have been among the first four subjects tested in an evening." December 19: "Feel fine and 'dandy' to-night; have felt pretty good all along, sometimes better than at other times but that just happens anyhow." February 2: "The chief inconvenience of the whole experiment has been the necessity of saving urine and feces and having only one place where this could be put. Besides my studies I manage the college store and am busy every minute of the day. There is no time for me to think about being hungry. I believe that it is because of this extra light physical occupation that I have not noticed the hunger and unpleasantness so much as some of the other subjects. As I have looked over the individuals of Squad A, I believe the men who are worried the most, and seem the most irritable, are those who have the least to do. Some of these subjects get through with their work in the afternoon at 3 o'clock and have nothing to do until supper but study and think how hungry they are. I believe that if I had to study during those periods I would notice the hunger too, but I am active, having to wait on customers, and subject to the demands of other people and my attention is occupied." February 8: "Now on the full and uncontrolled diet I am not quite so keen mentally as during the first part of the experiment. Immediately after the experiment was finished and when I began eating heartily again I had a tremendous tendency for drowsiness following meals when attending classes. This is passing off, but has not entirely disappeared."

Pec.—November 10: "Think I am keener mentally than when on full diet. It teaches a fellow a lot, particularly how much he can stand." January 26: "I am quite fit for mental work." February 2: "Am feeling rather better, continually improving; think I grow more fit all the time. During the diet I have not required so much sleep as usual." February 8: "I am sleeping all the time now on the uncontrolled eating. During the experiment there were a couple of papers on which I did not get my usual B mark, otherwise I think my work was normal." We believe that *Pec* was throughout the entire experiment the most optimistic subject of the entire group, but he talked the most about food.

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[1]The reader should bear in mind as he goes over this testimony that the experiment ended the morning of February 3, 1918. Any comments dated later than this were in the post-diet period, when the subjects were eating uncontrolled.

Gar.—November 10: "Have noticed no particular difference in mental ability; I tire easier when sitting in a chair studying." December 19: "Am looking forward to to-morrow morning" (Sunday uncontrolled dinner). January 6: "I feel all right, considering I am the last man to be tested to-night. This week I have been normal in every way; no trouble at all." February 2: "During the experiment I have been able to do my studying as well as usual, but it has not been so with my physical work. I do not seem to require so much sleep as I used to when on full diet. I believe this diminished sleep requirement is related to the diet. Lately I have had something of a 'don't care' attitude in relation to school work and the experiment also. This may possibly be due in part to the general disorganization of the school work on account of the war." February 8: "There was a definite change in the mental disposition with the diet; crabbedness and irritability developed after about the first 2 weeks and continued mostly during the experiment. So far as I was able to note there was no particular change in the ability to study, except as would be associated with some physical weaknesses."

Gul.—November 10: "Believe I am mentally keener than when on full diet. I can study for an examination to better advantage now." February 2: "Have noticed no difficulty or detriment to my mental work while on the diet. In the two years previous I have had a great deal of difficulty in keeping awake in classes, particularly after dinner and breakfast. This year I have not dozed off in a class any time during the experiment; absolutely no inclination to sleep during class lectures. In this way the diet has made me more efficient in my college work." February 8: "I feel 'logy'; it is hard for me to keep awake in class now that I am eating uncontrolled. This morning I was sound asleep in both classes; on the other hand, I have noticed that I do not sleep well at night; I wake up earlier and do not want to."

Kon.—February 2: "The chief inconvenience of the experiment has been the weakness and of course the hunger." February 8: "I can now study to better advantage, inasmuch as I do not have the feelings of weakness and the distracting desire for food."

Moy.—January 26: "During the week I have had no desire whatever to study; the condition is partly due, no doubt, to the realization that the experiment is about to end." February 2: "The inconvenience of the experiment consists largely in the time required, the getting up early in the morning, which necessitated earlier retiring, and also the time at week-ends for coming down to Boston for the Laboratory experiments there. My studying has been just about the same as last year but I think it has required more will power to stick to it." February 8: "Since the experiment I have been able to work as well as, I would not say better, than when on diet, but at least I can study later, *i. e.*, until 12 o'clock, without weariness. Of course it is not necessary for me to rise so early now. During the experiment when I was hungry I found it most satisfactory to run the typewriter or do some such work rather than try to study. It seemed to me that I could do as much on Sunday afternoon after the uncontrolled meal as I could do in all the rest of the week." May 21: "Looking back over the experiment, it seems that perhaps the men were more or less 'scouting' for trouble when they were on the diet. They were noticing many subjective feelings that at other times would receive but very slight, if any, attention. However, the feeling of weakness or faintness was so prominent and so frequently present that there is no doubting its connection with the experiment. There was also a change in mental attitude. As I told you during that period, I was said by some to be the most crabbed

man in school, and since the experiment ended many have remarked that I acted more like myself. I realize that during the experiment I was more critical and irritable and more ready to pick other people to pieces, and since the uncontrolled eating I have felt different toward my associates. Since I have as much or more work to do now than I did during the diet experiment, I can not believe that it was just the details of the experiment that produced this condition, but think it must have been the reduction in food that caused the increase in irritability. The physical weakness might also act in this way. During the experiment there were several times at the dining-hall when some amusing incidents happened, but they did not appeal to us as being particularly funny, as they would do now; we seemed to have a different and more serious mental attitude. I cared nothing at all for going to shows, which now and before the diet were very attractive to me."

Pea.—November 24: "The first three days of this week I could not study." December 8: "Not much ambition for study." January 12: "I have no ambition to sit and study; do not feel nearly so good as when I was eating full diet during the Christmas vacation." February 8: "Wednesday morning I went to sleep in class after the Tuesday evening banquet at Peckham's; I have not noticed any particular change in my studies yet." May 22: While the men would stand a good deal of 'kidding' among themselves, from their squad associates, they were more easily irritated, I think; some of them were judged by outside men to be very crabbed indeed. For example, some of the freshmen who entered college this fall, and had never known the men before, judged their dispositions on the basis of what they found them to be during the experiment; since the experiment has ended some of them have remarked at the considerable change they have found in us and expressed surprise at their previous misjudgment."

Can.—November 10: "Thinks his mind may be somewhat clearer than when eating uncontrolled." December 19: Felt good for the most part of this week; studied hard and long last night (until 12 o'clock); feels better than on any previous visit to Boston. February 2: "I think that in general the experiment has caused some decline in efficiency in studying; aside from this and the physical weakness the chief thing noted was the inconvenience of the experiment and the feeling of restraint of having always to stop and consider whether I can do this or that; then there was the trouble of collection of urine and feces." February 8: "I find that I can keep awake, study better, and pay better attention in class than I could on the diet; I have headache and a tired feeling in my eyes as during the experiment." May 22: "Your insistence that the talk about crabbedness is just a joke is wrong. Perhaps crabbedness is not the right word; I know of no better one to express it. The men were certainly more easily irritated during the period of the diet. Things which now appear to be small and insignificant were at that time exceedingly irritating and caused us to complain, particularly in reference to the amount of the food at the table. Our irritability was a subject of common remark among our outside friends; there were individual differences naturally; some of the men were easier to get on with than others. I think a good deal depended upon the scientific interest that the individual had in the experiment and his trying to look at the matter objectively. I believe you would have much more difficulty in trying to conduct the experiment with a group of men who had no scientific interest in the problem and whose enthusiasm for research was not aroused. I am under the impression that my mind was a little clearer for purposes of work during the diet period, but it was not sup-

ported by the endurance on the physical side which made long, continuous study possible."

Spe.—"I feel definitely that my fall term of school would have been better had it not been for the experiment. The condition can not be wholly laid to the diet. The interruptions caused by the trips to Boston every other week were rather serious in reference to any school work. While of course the men would not have been studying a great deal on Saturday and Sunday, yet the trip away from school and the anticipation of these week-ends was something of a disturbance to studying. During the fall term I had to force myself more than usual to accomplish my necessary work. Because of my illness I can not give any definite idea about the diet and my condition in the winter term."

Bro.—November 10: No change noted in mental ability. January 12: "I feel good to-night, but the past few days I have been unable to study much; I do not have enough to eat." January 26: "I feel better than usual to-night, with the prospect of only one week more of the experiment; nothing special to note, except that I have not accomplished much work." February 8: "During the experiment I found that I could study fairly well immediately following meals, but after a time or when it got to be an hour until the next meal I was hungry and could not sit quietly and study. At such times I found it better to get up and occupy myself in arranging the books on the library shelves." (*Bro* was assistant librarian. See subject's comment on diet, p. 279.) May 21: "During the experiment my mental attitude was such that I thought the studies were interfered with by the diet. As I look on it now, it does not seem that there was much interference aside from the fact that one's interest and attention were more or less occupied with the experiment and with looking forward to meal times. It was just as if a basket-ball game were about to occur; you simply could not help thinking of it frequently. Concerning the matter of mental attitude or disposition, I think it was not a joke but a reality, and in all probability associated with the reduction in diet, although there is possibly some connection with the occasional lack of sleep. We called this condition 'crabbedness.' In my own case I had to work in the library each night until 10 o'clock and I had to get up earlier in the morning; there was no opportunity to make up for lost sleep, and this at times affected my mental attitude, which was frequently that of dissatisfaction and irritability. I recall, as was remarked by myself and others several times, that after Sunday, when the men had had a good meal (and more sleep), they would be decidedly changed in mental disposition and would hardly seem like the same individuals."

Vea.—February 2: The experiment has taken considerable of the subject's time and he thinks he has frequently been unable to study as well as usual. "Always thinking of eating". May 21: "Now on the uncontrolled diet it is much easier to do my college work from the standpoint that it is easier to concentrate my attention on it. When I sit down to work I do not continually think of the matter of food. There has been a definite change in mental disposition. Mr. X, who roomed near me, has often said lately, 'Why, Veal, there is 100 per cent change in you since you commenced eating. When you were on that experiment you used to come upstairs, slam your door shut, and commence studying, and you weren't at all sociable.' I also have noticed the change in this regard, but in the experiment it wasn't only just the matter of reduced food; it was the many little inconveniences in connection with the experiment, such as infringements upon the time of the men, so that they

could hardly have been expected to be otherwise than crabbed, and at times discontented."

COMMENTS OF COLLEGE INSTRUCTORS AND OTHERS.

There were a number of people in and about the college who looked upon the experiment as a more or less dangerous thing for the men who were serving as subjects. Fellow-students would inquire how the men felt, would watch them closely, and express themselves freely and strongly, usually in a way that was not very favorable to the reduced-diet feature of the experiment. The men were frequently asked if they did not feel almost starved. The outsider would suggest that he himself could not walk down the street if he had to live on so little food. A number of the men experienced considerable difficulty when they went home at the time of the Thanksgiving and Christmas vacations. Parents and friends complained at the loss of flesh which they observed and expressed solicitation as to the probable danger and the outcome of the whole affair. In one case a trained nurse, a friend of the family, tried to interfere, strongly urging that the young man should not be allowed to return to college if he persisted in continuing with this "foolish business." *Gul* reported to Mr. Fox, December 7, 1917, that a business man prominent in the Springfield boys' club work had offered his services, and those of some other influential friends to help get *Gul* off the "diet squad."

Another example of the interference from outside people was in the case of *Pec*. A physician whom he knew well said in the presence of himself and some members of his family that he should by all means drop out of the diet experiment, as he was taking great chances with his personal health and might almost any time find himself gripped by some disease. A day or so later *Pec* spoke of this incident and made the following remark to one of us:

"I feel bully, and what do I care about my looks, so long as I feel well and fit. We fellows are not suffering anything like the men in the trenches; the unusualness of the experiment is what challenges people's attention; they can't understand why one is willing voluntarily to go on the food reduction when there is plenty of food on all sides. I shall continue to strive for my 10 per cent weight loss and will say nothing about it to members of my family."

Professor Affleck, commenting upon the school work of the men of Squad A, said:

"I am sure these fellows did not try to use their diet-squad experience or service as an excuse in their college studies. It is my feeling that they wanted very much to show that they were just as good as ever, although on a reduced-diet condition. In their courses there was no special consideration given them by the members of the faculty."

Professor Berry made a number of pertinent comments concerning this phase of the investigation. He said in part:

"I feel sure that the members of Squad A were less affected by the psychological conditions pertaining to the diet and to the experiment in general than

most groups of men who undertake diet experiments. Usually, so far as my observation has been, the psychological influences play a very important rôle in dietetic experiments, particularly in the matter of muscular performance of men under these varied conditions. It is my conviction that the psychological element was less prominent in this experiment, and played a less important rôle than in any other case which has come to my attention. The men were commonly found to be somewhat irritable; they were 'touchy,' like wild cats. For example, it was necessary for me to speak to two of the men concerning a certain matter. I knew the men well and was surprised to find them so irritable and to act as they did on that occasion. I do not feel sure that all this is absolutely bound up with the change to a reduced diet, but it came about in connection with the experiment. With some men it may have been because of the necessity of getting up earlier, with somewhat less sleep, and other more or less aggravating things in connection with the experimental procedure. I believe you will find that there was no measureable difference in scholastic work. There was no tendency to try to pass in the fact of membership in Squad A as an excuse, and I believe firmly that there was no leniency on the part of the faculty in consideration of the fact that these men were serving on this squad. Possibly the time and the details in connection with the experiment may have engrossed the minds of some serving as subjects so that they appeared to take less interest in college activities, but in general it must be conceded that their work was normal."

CONCLUSIONS REGARDING PSYCHOLOGICAL ENVIRONMENT.

From the foregoing notes and comments it must be concluded that although the psychological conditions were probably as favorable at the International Y. M. C. A. College at Springfield for an experiment of this kind as would be found anywhere else, still there was a certain amount of opposition (negative suggestion) which had to be met by the men who were on the food reduction. The men could not live by themselves. It seems to us now that arrangements should have been made so that they could have had their meals separated from the other men rather than at a table in one corner of the main dining-room. This would have proved a double advantage: (1) the subjects would not have had continually before them the abundant food placed on other tables for their fellow-students, and (2) the other men could not have known how limited was the quantity of food allowed the low-diet subjects. Their dietetic régime and physical appearance were constantly topics of conversation for their fellows. In the nature of things comment would not be generally favorable or enthusiastic. The subjects were loyal and determined to see the experiment through to the end. Nevertheless, the comments of their friends could not but act upon the men as suggestions, and it seems only fair to believe that to some extent at least, these comments gave color to the personal impressions of some of the subjects regarding themselves. The psychological atmosphere, at least, outside the squad was charged with expectation of trouble. What others saw in them, the men, to some extent, may have come to see in themselves, but this matter of suggestion must not be pushed too far.

It must be remembered that these subjects were men, intelligent, and quite capable of forming independent judgment. They became to a great extent a gregarious group; there was a good deal of the spirit of caste and group pride. This engendered a certain amount of combative spirit not favorable for the operation of suggestions from the outside. Comment is practically unanimous as to the change in mental attitude and disposition accompanying the reduction in diet. The men were more irritable, more easily annoyed by each other and by outside associates.[1] As they expressed it, they were more "crabbed." They recognized this in themselves, and others recognized it. Those who had not known them before the beginning of the experiment and who formed opinions concerning them during that period were surprised to discover the difference after the men had begun eating uncontrolled. The men joked about their own irritability only because they recognized it and believed it to be a temporary condition from which they would rally when the food reduction was passed. It seems altogether probable that this irritability may have been due, at least in part, to other things besides the mere reduction in amount of food. However, the indications are that it was most prominent in those times when the body-weight was being actively reduced by an unusually low caloric intake, as in October and early November and also following the Christmas vacation in early January. In December and late January the men commented upon themselves in a much more pleasant way. When they were present at the Laboratory, they laughed and talked much more freely and seemed generally much less irritable, if not, indeed, entirely normal. The crabbedness, so-called, developed prominently in some of the members of Squad B during their 3 weeks' greatly restricted diet from January 8 to 28. Space will not permit giving their comments.

EFFECT ON MENTAL ATTITUDE.

No reader will doubt the fact that members of Squad A, during the experiment, sometimes found it more difficult to concentrate their attention upon their studies and to sit quietly at work. Who has not at times noted in himself greater difficulty in continuing at such work when the meal time was near at hand or when he was about to start on a journey? It must be apparent to anyone that there were many details about the experiment which called for the cooperation of the subjects, and so, for their attention. It was an added burden and interest which their fellows did not have to carry; it entailed many individual appointments and group meetings, as well as the regular trips to Boston, which occupied Saturday and a portion of Sunday.

[1] Langfeld reported depression and irritability in the case of L, who fasted 31 days at the Nutrition Laboratory (See Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 191). The experimental program no doubt became more monotonous in the fasting than in this low-diet investigation.

There were new apparatus and scientific methods for them to become acquainted with and interested in. These things could not otherwise than distract their attention somewhat from regular duties. Hence, when a man reports that he has not accomplished much studying during the previous days or has not had much desire to study, those who are acquainted with college life will recognize at once that this is not a condition peculiar to a restricted diet. Considering the experiment as a whole, the men did much more than they could originally have expected to be called on to do, but even so, there was very little complaining, and it was always easy to cheer them up and enlist their support. They proceeded with their college work as usual, regarded the whole thing somewhat as a joke, and made fun of themselves and of others in connection with the matter of eating. Not one of the men would be willing to have the experience omitted from his life.[1]

Aside from some feelings of weakness and discomfiture especially prominent at times of active weight reduction, and some scattering of attention incident to the experiment, the reduced diet as such seems to have had no detrimental influence on the ability for mental work. Several subjects were convinced that their minds were clearer during the diet period and that they were relieved from the annoying tendency to sleep after meals, which tendency returned and was prominent with the excessive eating following the experiment. Some variety of work was found particularly desirable. If at those times, when thoughts of food were especially persistent, and hunger prominent, the subject had some light physical activity to which he could turn, the time until the next meal seemed greatly shortened.

EFFECT ON SCHOLASTIC STANDING.

To verify the personal impressions regarding the scholastic work of the men who served as subjects in the experiment, we have the more or less objective data of the term grades in the several college courses which were taken. The experiment lasted from October 4 to February 3. The college year is divided into three terms—fall term, from September 19 to December 21; winter term, from January 3 to March 22; and spring term, from April 2 to June 1. The fall term and the first part of the winter term were thus included in the diet period. In table 200 the average term grades for the fall and winter in all the courses taken are compared for each subject with the average of all the grades which the subject had received in all the courses taken previous to

[1]Many things concerning the light side of the experiment and the attitude of the men to it could be mentioned. On the floor of the library at the Nutrition Laboratory, one Monday morning, one of us picked up a slip of paper bearing the following couplet: "Die, die, Diet Squad; Shy, shy, shy a 'pod,'" by which it is meant to be indicated that the girth has been remarkably reduced. Squad A, when the experiment was nearing the close placed a calendar over their table in the dining hall, which bore in large letters the words: "Ten days, and we eat." Each day, to the accompaniment of applause and congratulations, the number of days was decreased one.

September 1917. Of Squad A, 9 men were from the senior class, but *Fre* should not be counted in any comparison, since he served in the squad so short a time; there are thus 8 men whose records are comparable. Of these, 4 (*Can*, *Gul*, *Pec*, and *Vea*) show average marks for the diet period which are slightly below their average for all courses preceding September 1917. There are 4 (*Bro*, *Gar*, *Moy*, and *Tom*) who show marks as good or better for the diet period. Changes are not large in any case, the largest is one of 4 per cent in the case of *Moy*, whose previous average grade was 87 and whose average grade during the low diet was 91. The whole group of 8 senior subjects taken together show average grades which are identical for both periods, that is, 88.6 per cent. There were 31 other men in the senior class. The average grade for all of these men, prior to September 1917, was 86.3 per cent, and for the same group, during the period of the experiment, the average was 84.3 per cent. There was thus an average

TABLE 200.—*Average grades of members of Squad A during the reduced-diet experiment contrasted with their previous grades, and with those of their fellow classmen.*

Members of Squad A contrasted with average for the other men in their classes.	Average grade in courses taken prior to September 1917.	Average grade in courses taken in fall and winter terms of 1917–18.
Squad A—Seniors:	*p. ct.*	*p. ct.*
Bro	92	92
Can	88	85
Gar	88	91
Gul	87	84
Moy	87	91
Pec	91	89
Tom	90	92
Vea	86	85
Average for the above 8 subjects	88.6	88.6
Average for the 31 other seniors	86.3	84.3
Squad A—Sophomores:		
Mon	89	92
Pea	83	88
Spe	79	87
Average for the above 3 subjects	83.7	89.0
Average for the 27 other sophomores	83.0	87.0

decrement of 2 per cent for those who were not subjects. If this tendency of the class as a whole during the first two terms of this year as compared to the record for previous years is contrasted with the average record for the 8 senior men who were subjects in Squad A, it is perfectly justifiable to say that these men did not do work that was inferior to their previous college work, and their performance was in no way below that of their fellows. Three of the subjects of Squad A were classified as sophomores; these were *Mon*, *Pea*, and *Spe*, as

shown in table 200. The average grade in the case of these 3 men shows in each instance a better average grade during the period of the experiment, with the result that the 3 men have an average grade of 83.7 per cent for courses prior to September 1917, and for courses during the experiment, 89.0 per cent, an average difference of 5 per cent in favor of the work done during the experiment. The average for 27 fellow-classmen shows an average grade of 83.0 per cent prior to September and an average during the experimental period of 87 per cent. Here is a difference of 4 per cent in favor of the work done this college year. The three sophomores in Squad A, therefore, show the same tendency as the rest of their class, but slightly more marked. Hence after a careful analysis of the term grades for the many courses which had previously been completed and others which were taken during the period of the experiment by these men, it was found that, as a group, during the 4 months' period of reduced diet, they kept their college work up to their own previous standard, and were not inferior to their fellow classmen. The statement of Professor Berry and some of the men that the college work was of usual standard is therefore clearly verified.

GENERAL POST-EXPERIMENTAL HISTORY.

An important part of our records of this research is the post-experimental history of the men undergoing this experience. Questions which may fairly be asked are: What condition were these men in at the end of the long test? What was their history subsequent to the restriction in food? Were there any permanent effects of the low diet? Did the men subsequently change their dietetic habits on account of their experience?

Owing to the special conditions obtaining at the Y. M. C. A. College in the spring of 1918, when a number of the men left college for Y. M. C. A. military service, it became impossible to obtain such information for all of the men. However, a number of them were seen personally by one of us on a visit to Springfield May 21 to 22, and records were made of their condition at that time. More or less data have also been obtained through correspondence. A special effort has been made to find whether a permanent effect of the low diet was noted by the men themselves. Much of this information has already been given in previous sections, particularly in the section on diet. (See p. 272.)

One general feature of the post-experimental history is the excess eating immediately indulged in by the men. Considerable practical experience has shown that there is danger in taking a large meal immediately after prolonged starvation or even after a period of undernutrition. Evidence on this point has already been given, showing that when the men were allowed uncontrolled diet, they almost invariably overate, notwithstanding repeated cautions. This frequently

resulted the following day in pain in the abdomen or diarrhea and general discomfort. This tendency of the men to eat largely after fast is in full conformity with statements made by Professor Pawlow to the effect that more or less gross feeding usually followed Russian fasts. (See p. 203).

Although all of the subjects were frequently told that if they desired to increase their diet at the conclusion of the test, they should do so slowly and carefully, and not indulge in immoderate amounts of food, the over-indulgence in food was general among the men. As a result, a considerable number of them suffered from abdominal pain, colic, and diarrhea. The experiment ended Sunday morning, February 3. In spite of excessive eating on Sunday and digestive disturbance on Monday and Tuesday, all of the men attended a banquet February 5 given by one of Squad A to the squad as a whole. At this banquet they ate inordinately.

The most direct evidence that we have of the excess eating following the cessation of the diet is the great and rapid rise in the body-weight shown in figures 57 to 68 and discussed in the section on body-weight. In practically every instance the weight prior to the beginning of the experiment was reached almost immediately and was usually materially

TABLE 201.—*Increases in body-weight after resumption of normal diet—Squad A.*

Subject.	Initial weight. (Sept. 30, 1917.)	Final weight with reduced diet. (Feb. 3, 1918.)	Initial weight regained.		Maximum during post-experimental period.	
			Date.	Days required.	Date.	Weight.
	kg.	*kg.*	1918.		1918.	*kg.*
Bro.......	61.8	54.4	Feb. 13	10	Mar. 11, Apr. 29	63.0
Can.......	79.8	69.3	Feb. 21	18	May 23	81.8
Gar.......	71.3	63.0	Feb. 25	22	Mar. 11, 14	72.5
Gul.......	66.8	61.0	Feb. 16	13	Feb. 21 and Mar. 14	69.5
Mon......	68.8	60.6	Feb. 20	17	Mar. 11	70.0
Moy......	63.5	57.8	Feb. 8	5	Apr. 29	71.5
Pea.......	69.3	61.3	Feb. 13	10	Mar. 11, 14	74.0
Pec.......	64.3	59.1	Feb. 13	10	Mar. 14	71.5
Tom......	59.5	55.1	Feb. 13	10	May 23	64.9
Vea.......	65.8	58.5	Feb. 18	15	May 22	71.2
Av.....	67.1	60.0	....	13	....	71.0

exceeded. This is shown in table 201, in which are given the initial weight of the members of Squad A prior to the experiment, the weight at the end of the experiment, the date on which the initial weight was regained, with the number of days required for this, and the subsequent maximum weight, with the date upon which it was recorded.

No evidence was obtained that these men, with the possible exception of *Moy* and *Bro*, acquired new dietetic habits or adjusted them-

selves to a lower food intake as a result of the experiment. The circumstances militated against this. In the first place, the men craved food after the restricted diet and especially desired sweets and accessory foods of all kinds. Secondly, subsequent to the research, they were liberally supplied with food in the dining-hall and ate with their college mates without restriction. Environment more than physiological demand was the controlling influence.

On May 22, 1918, all of the men were reported to be in excellent physical condition. But 6 of Squad A were then in college, the others having been called away for duty elsewhere, one of these only temporarily. After May 22, 1918, it was extremely difficult to keep in touch with the men, owing to their being so widely scattered on account of war conditions. We have, through one channel or another, secured the following notes regarding the members of the two squads. All of this information demonstrates success in their various lines of activity and would seem to indicate that the men experienced no ill effects from the experiment.

Bro.—May 22: Still in college and carrying on his usual work as assistant librarian; in excellent health. Eating only two meals a day, omitting dinner; thought he was taking less food than normally. Did this for economy, but not entirely as he thought he was better for it. Later in 1918 was in Y.M.C.A. work in the army.

Can.—May 22: In college. Had been eating too much and felt need of reduction. Was trying to take only one helping at table. Was married after leaving college, and drafted. In excellent health June 1919; nude weight at that time, 85.5 kg., *i. e.*, 18.0 kg. overweight.

Kon.—Was compelled to leave college shortly after the end of the experiment on account of accident to his father. According to information obtained on May 22, he subsequently worked hard in a mine belonging to his father, was gaining in weight, and was feeling very well. Later went to the University of Toronto to train for aviation section of the Army Signal Corps. In the spring of 1919 was physical director of the Young Men's Christian Association, Middletown, Ohio.

Gar.—Was drafted and went to Camp Taylor in Kentucky in April; was in excellent physical condition on leaving college. Married April 23, 1918.

Gul.—Drafted and left college March 15, 1918, for a few weeks at home in North Dakota before going into the army; while at home worked on the farm. Later went to Camp Dodge, Iowa, as member of the Engineer Corps; afterwards second lieutenant at Camp Hancock, Georgia. Was feeling fine when last heard from. In January 1919 was out of the Army and connected with the Minneapolis, St. Paul, and Sault Ste. Marie R. R. in South Dakota.

Mon.—Left college and went to France in May to enter military Y.M.C.A. work as physical director. Was married before he went. In January 1919 was still in France.

Moy.—Passed local district medical examination for military qualifications about the middle of March, in Springfield. There was no question as to his physical condition at that time. May 22, thought his record with hand

dynamometer was better than during the low-diet experiment. Was going without supper to save time and money; thought he was eating less than previous to experiment. Appetite less keen since omitting supper. Ate three meals a day up to April 3. During the diet experiment he tried to make the college swimming team, but was too slow. After experiment, he tried again but was too fat; later trained down and made the team. Died of influenza and pneumonia at the Great Lakes Naval Training Station, Great Lakes, Illinois, in the fall of 1918.

Pea.—May 21, in college. Said that after the diet experiment he became so heavy that he could not win a place on the track team in the distance run. Was too heavy for the 2-mile race and was trained for the half-mile. In two track meets he did not win a place, although he could reasonably have been expected to have done so, as the year before he had been captain of the track team and best man on the team. His failure was considered as being due to putting on too much flesh after the low diet. When seen May 21, had attended a dance the night before and danced hard until after 12 o'clock. Had influenza and pneumonia in the fall of 1918, but recovered. In January 1919 was lieutenant in the U. S. infantry. April 1919 in Italy as athletic director and organizer for the Young Men's Christian Association.

Pec.—Went to France early in April for military Y.M.C.A. service. The vessel he sailed on was torpedoed, and although he was the last man to be awakened, he succeeded in saving his own life and that of another man. In January 1919 was still in France.

Spe.—Returned to college on April 2, 1918. Reported to be in good condition. Owing to his serious illness, his body-weight in the spring was essentially that at the time the experiment was begun. Obviously his illness played an important rôle in his post-diet experience and undoubtedly resulted in his more ready adjustment to a normal diet than was the case with the other men. Later in the year was second lieutenant in the Students' Army Training Corps, Columbia University. In the spring of 1919, still in college.

Tom.—Married on March 24, 1918. On May 22 was temporarily away from college, assisting in a Red Cross drive at Yonkers, New York, for a week. This work was done in addition to his regular college duties. Was intending to finish his course. Had rallied from his operation, and during the few weeks previous had been in the gymnasium, although as a result of his operation he had not been able to do all the gymnasium work. In general, he seemed to be in good physical condition.

Vea.—In college May 21. Later, was drafted for the Army and in June 1918, was at Camp Upton, New York; afterwards went to France as corporal in the infantry and had considerable service in the front lines. In January 1919 was still in France.

Squad B.—All of the men in Squad B were in one branch or another of the Government service during the war. *Fis*, *Sch*, and *Van* were in the army (*Sch* in the Medical Corps, and *Van* second lieutenant assigned to the 63rd Pioneer Infantry); *Sne*, *Kim*, *Lon*, and *Tho* were in the navy; *How*, *Ham*, *Liv*, and *Wil* were in the Students' Army Training Corps.

In March 1919 six of the men were in college (*Fis*, *How*, *Ham*, *Liv*, *Van*, and *Wil*), were active in athletics, and in excellent health. *Sne* and *Tho* had graduated. *Kim*, *Lon*, *Sne*, and *Tho* were still in the navy. *Kim* and *Lon* expected to return to college when released, *Sne* was an ensign, and *Tho* was training for a commission. Two of the men in Squad B had married (*Fis* and *Sch*).

SUMMARY OF RESULTS AND GENERAL CONSIDERATIONS.

From the large mass of data that we have attempted to analyze in this report, certain very striking factors stand out above all others. While on the reduced diet these men underwent profound metabolic changes, which were indicated not simply by the losses in weight but also by alterations in pulse-rate, in blood pressure, to a slight extent in respiration rate, and more especially in the gaseous metabolism.

CAUSE FOR DEPRESSION IN METABOLISM.

The depression in the total metabolism is, without doubt, the most prominent feature of the entire research, particularly as it was accompanied by a depression in other physiological factors, such as blood pressure and pulse-rate. Loewy and Zuntz[1] also noted a lowered metabolism and give two possible explanations of it. One was that the depression may have been wholly due to a lowered protein intake, the other that there may have been a very considerable decrease in the active cell-substance. The first of these two hypotheses they dismiss, because Loewy, from the nitrogen excretion of the urine, showed that he was living upon a distinctly high nitrogen level. The explanation of Loewy and Zuntz thus rests solely upon the hypothesis that there was a considerable loss of active cell-substance, and they conclude that when the protein content of the diet is large and the caloric intake is insufficient it is impossible to prevent the disintegration of active body-substance. None of our men happened to have as high a nitrogen excretion as that of Loewy, but with some it was fairly large and with others fairly small. Consequently we do not believe that the protein intake of itself played any particular rôle in this case. Loewy and Zuntz naturally lacked demonstration of the loss of protein from the body.

One of the possible explanations of this lowered metabolism is that with a weight-loss there is less work for the musculature to perform in its ordinary activities—less weight to be lifted and less weight to be moved. This may even apply in the case of respiratory and heart muscles. A lower metabolism as a result of reducing the load to be moved would therefore be expected.

A second possible explanation is that with the reduction in diet, and consequent loss of body-weight, there may be a removal of fat from the tissues of the cells that makes the muscles somewhat more flexible, capable of more severe work and greater efficiency. This is perhaps in part comparable to a certain phase of athletic training, which com-

[1]Loewy and Zuntz, Berl. klin. Wochenschr., 1916, **53**, p. 825. As this monograph goes into page proof, our attention has been called to a second article by these authors (Zuntz and Loewy, Weitere Untersuchungen über den Einfluss der Kriegskost auf den Stoffwechsel, Biochem. Zeitschr., 1918, **90**, p. 244), cited in an editorial in the Journ. Am. Med. Assoc., 1919, **72**, p. 574. We are not able to see the original article and in any event it is too late for its analysis in this report.

bines the removal of fat by excessive activity with the enlargement of the muscles with practice. Comments made in gymnasium classes implied that the men found the muscles were more free when they were on the reduced diet than when they were on uncontrolled diet.

Since, however, the changes in the metabolism were accompanied in practically all cases by a large loss of nitrogen from the body, the correlation of the nitrogen loss with the lowered metabolism is a natural procedure. With Squad B the general picture is much the same as with Squad A, although as the weight loss and the nitrogen loss were only about one-half those of Squad A, the depressions are not so sharply accentuated as with that squad.

An inspection of the nitrogen figures leads us to believe, however, that the most obvious cause for this lower metabolism is the removal of some 175 or more grams of nitrogen from the bodies of these men, resulting in a withdrawal from the fluids bathing the cells of a large amount of nitrogenous material. This material, which acts as a stimulus to cellular activity, is probably of an acid nature. It is clear that a careful chemical analysis of the blood should have been made.

It is of prime importance to note that in this whole series of experiments with the 25 or more men involved, the picture exhibited by the individual men is almost identical with that shown by the group as a whole. In other words, we have here no exceptions. It is extremely unfortunate that all of the initial members of Squad A could not have completed the 4 months' test. This would have greatly simplified the averaging of the results. Of the original members of Squad A, however, there were 9 men who went through the entire period without a break; we have therefore averaged the values for the most important findings for these 9 men and present these averages in the form of a chart. (See fig. 124.) It should be emphasized at this point that our basal tables and our derived tables for the several factors studied are made up from an analysis of the situation as presented by *all the members* of both squads, and the conclusions are drawn from these figures. The curves given in this chart, however, are drawn from the picture presented by only *9 members of Squad A* [1] So far as we can see, there is little, if any, change in the general appearance of the picture or the interpretation of the data as a result of this curtailment in the number of men. For a general picture showing the influence of low diet upon all the physiological factors mentioned, a chart is preeminently desirable, but in making such a chart it is necessary to average values in so far as possible for the same number of individuals. The body-weight curve, representing a composite curve of the weight changes of 9 men, has a particular interest in that the distinctive features brought out in discussing the individual body-weight curves, namely, the post-Sunday

[1]The 9 men whose data were used for the chart in figure 124 are as follows; *Bro, Can, Gar, Gul, Mon, Moy, Pea, Pec,* and *Vea.*

rises and the post-Christmas rise, are all clearly shown in this curve. The striking increase in body-weight following the resumption of normal diet is also prominent.

Although the net caloric intake has been shown on the individual body-weight curves, the average values for these 9 men are here given in blocks closely associated with the average body-weight curve. The difficulty of securing evidence regarding the net caloric intake at the maintenance weight level is more clearly brought out in this composite curve than with the individual curves, for one would expect a smoothing of the curve, indicating even more than is here shown that weight maintenance was obtained in December and again in the latter part of January. Even with the best possible food adjustment, which it will be recalled was specifically planned to maintain the weight at a constant level, we find that the average value for the 9 men shows considerable fluctuation. Yet we see no reason for altering our original statement that during December and the latter part of January these men were essentially at weight maintenance. As was pointed out in the earlier discussion, a change of 1 kg. may not be significant, owing to the large water content of the body, and it is by no means a certain indication of changes in organized body-tissue. The energy intake at the weight level is for the December period 2,200 calories and for the January period 1,950 calories. The average for these 9 men for these two periods is therefore 2,075 calories, which is but little above the average value for the entire squad, namely, 1,967 calories.

It is important to note that in this chart, as in the individual body-weight charts, the net energy intake for the first few days in October, which is here represented as 3,100 calories, should in all probability be nearer 4,000 calories, and would in consequence normally occupy a higher block and correspond more nearly to the general trend of the body-weight curve.

In spite of the striking changes in the net energy intake, as shown by the blocks at the bottom of the chart, the nitrogen in the food represents fluctuations by no means comparable to the total energy. The general contour of the series of blocks indicates that the nitrogen of the diet was not on a particularly low level, but averages about 10.5 grams. The section of the curve for the last few days of the experiment shows a distinctly high nitrogen intake, this being higher than at any other time during the observation, save for the first week of uncontrolled normal diet.

In striking contrast to the nitrogen in the food is the rather level curve for the nitrogen in the urine; that is, in spite of the relatively enormous alterations in nitrogen in intake, we find the nitrogen in urine remains reasonably constant, the lowest point of the curve appearing a few days following November 26. Here again it is well to emphasize the fact brought out in the study of both Squads A and B

that the relative constancy of the nitrogen excretion in the urine under very marked change in intake is one of the surprising features of the research.

The comparison between the nitrogen of the food and the nitrogen in urine leads, of course, to the consideration of the large nitrogen losses. These are so significant and of such magnitude that we have deemed it advisable to plot them in the form of a curve showing the accumulative nitrogen loss, which is a curve that continues downward as the experiment progresses. This appears near the lower part of the chart and shows a final loss at the end of the experiment of not far from 175 grams of nitrogen for the average of 9 men. Sufficient attention has been called in the earlier text to the difficulties of accurately estimating the total nitrogen loss, owing to the uncontrolled days, on the one hand, and to the loss through the skin and perspiration on the other.

One of the most important physiological measurements showing general condition is the blood pressure, which is frequently reported with these men. The average blood-pressure curves show systolic, diastolic, and pulse pressure. All three curves have much the same trend, namely, a distinct falling off up to November 25, with a tendency for minimum values appearing shortly thereafter, then a slight rise in systolic and diastolic pressure to January 12, after which, although the systolic and diastolic pressure curves are parallel, the pulse pressure is in the opposite direction. Pronounced reductions of all three factors are worthy of special emphasis.

Pulse-rates were recorded frequently throughout the entire series under several conditions. The normal pulse-rate was observed with the subject lying in the morning in the post-absorptive condition. (See lower part of figure 124.) The curve shows a distinct tendency towards a fall in the first part of the experiment, a plateau at the low level in November, a sharp fall from a higher level following the Christmas recess, and a slight rise toward the end of the experiment.

The important relationship between the pulse-rate and muscular work is indicated by the records computed from Professor Johnson's data, with the subject lying 1 minute before work, 1 minute after work, and the percentage increase 1 minute after work. The pulse-rate 1 minute before work, although at a distinctly higher level, is obviously more or less comparable with the pulse-rate obtained in the morning with the subject in the post-absorptive condition. The form of the two curves is not unlike, the pulse-rate 1 minute before work showing a decrease in the early part of the experiment, followed by a pronounced rise, with a striking increase immediately after the diet restriction ceased. This great increase was followed by a distinct drop following more normal eating.

The pulse for 1 minute after work on the ergometer shows up to December 8 very much the same trend as do the other pulse-rate curves. On December 10 there is a large increase and immediately following the return from the Christmas recess there is a pronounced fall to the end of the restricted-diet period. The striking increase after the restricted diet ends, noted with the pulse 1 minute before work, is here even more accentuated.

As an index of the reaction of the heart to a definite amount of work, the percentage increase in the pulse-rate 1 minute after work ceases is of interest, this representing in a sense the increment of the pulse-rate expressed in percentages for accomplishing a definite amount of work. This curve shows an extremely irregular contour, the highest point being reached about November 15, the lowest point just before the end of the observations. In comparing the number of minutes required for the pulse-rate to return to the normal after a definite amount of work, it appears that the curve for this factor and that for the percentage increase 1 minute after the ergometer riding are more or less parallel, and this is true until the return from the Christmas recess. After this point the curves are in most instances opposed to each other. It is worthy of note that with the percentage increase 1 minute after work there is a great decrease on the whole after the diet restriction ceases and a high point in the time required for the pulse-rate to return to normal after work, although the absolute maximum is noted on November 14.

Since the gaseous metabolism plays so important a rôle in our study of the total metabolism, the factors entering into the gaseous metabolism, as well as the heat calculations therefrom, are represented by several curves in figure 124.

The average total basal heat production for this group of men per 24 hours may first be considered. Although there are very wide fluctuations from day to day, as indicated by the rise and fall in the curve, the general trend is distinctly downward, save for the high points on November 26 and December 10 following the uncontrolled Sundays and likewise the initial high point following the Christmas recess in the early part of January. Thereafter during January there is a steady decline, with a minimum on January 24 and a tendency to a slight rise thereafter. Since the body-weight was changing throughout the experiment, it is quite obvious that not only the total heat per 24 hours should be considered, but particularly the heat per unit of body-weight and likewise in this homogeneous group of subjects the heat per square meter of body-surface. The curves assigned to both of these factors show remarkable uniformity and agree in the main with the total heat-production curves—a pronounced drop during the first weeks of the season, sharp rises on November 26, December 10, and after the Christ-

mas recess, with a tendency to fall thereafter, and a fair approximation to a level at the end of the period.

When one considers these measurements of metabolism as a whole and the factors of circulation and respiration, it is astonishing what regular pictures they present when compared with the body-weight and, indeed, with the intake of food. The entire picture shows the depression of all activities during the early part of the session, characteristic rises following the recuperation period during the Christmas recess, a rather sharp fall thereafter, with a tendency towards constancy during the month of January. Certain observations that were made after the period of low diet ceased show a pronounced rise in the pulse-rate, lying before riding, the pulse-rate 1 minute after riding on the ergometer, and a very great rise in the body-weight. This implies that the correlation between actual body-weight and these various factors is very close.

It is certainly clear that during the period of transition, when the body-weight was rapidly falling, all of the factors of metabolism and all of the physiological activities were markedly depressed. When the body-weight finally reached a level, namely, during the month of December and the latter part of January, there was a distinct tendency for these activities also to assume a level, although they are by no means absolutely comparable. With the resumption of increased food intake at the end of the experiment, the two factors measured both followed the body-weight, indicating a pronounced increase.

It is also of great significance to note here the two neuro-muscular processes that have been charted, namely, the number of finger movements made in 10 seconds and the eye movements as recorded in the length of time required to move the eye through an arc of 40°. The speed of the finger movements, which has been shown in an earlier research from this Laboratory to be representative of motor coordination, decreased definitely. At about the Christmas recess there was somewhat of a recovery and evidence of a distinct spurt on the last day of the experiment. The eye movements, which have likewise been shown to be characteristic motor coordinations, distinctly increase in the time required for a definite movement from the day when the observations were begun, namely, October 28, to the last day of the series, this increase being progressive and reasonably regular.

The general picture presented by this chart is a depression of the physiological, particularly the metabolic, activities, throughout the greater part of the time. This is likewise true with regard to the two neuro-muscular processes here charted. That these are in large part affected by the state of nutrition is shown by the close relationship between the various curves and the body-weight curves, and, incidentally, the food-intake curve. In view of the close relationship between pulse-rate and metabolism, and in the absence of metabolism measure-

ments after the return to normal diet, the great increase in pulse-rate accompanying the great increase in body-weight may legitimately indicate that there was likewise a corresponding increase in the metabolic processes, in all probability closely correlated with the actual body-weight curves. It is important to note, however, that the body-weight curves here have no particular significance *per se* other than as a general index of the nutritional level upon which the body was living.

Finally, attention must be again called to the pronounced accumulative loss of nitrogen with low diet, averaging for these 9 men 175 grams at the end of the 4 months of the experiment.

In interpreting this loss, we must give consideration to the figures obtained for *Tom*, although he was not included in the chart. Tom's nitrogen loss was but 45.74 grams for the entire period, while the average for the other 11 men was 175.0 grams.[1] If our theory with regard to the nitrogen stimulation is sound, one would expect normally to find a less pronounced effect on metabolism with *Tom* than with any of the other men. As the data were being prepared it appeared that there was no profound difference between the men on this basis. A more careful analysis of the data given for *Tom* shows that the total metabolism of this subject fell off very markedly, as indeed did the metabolism per kilogram of body-weight and per square meter of body-surface. Hence we have with *Tom* identically the same picture noted with all the other members of the squad, although his loss of nitrogen was on the whole but one-fourth that of the average for the 11 other members of the squad and but one-fifth that of 3 other members of the squad. At first sight this would appear to be a distinct argument against the nitrogen-stimulation theory. On the other hand, we must point out that, at least during January, *Tom* was in a distinctly poor physical condition. In fact, he was quite wretched during part of December and was operated on for hemorrhoids. No member of the squad seemed to find more difficulty in reducing his weight than he did. He presented a distinctly exceptional case throughout the entire period of observation. As frequently stated, he was the most sedentary in habit of the men in the squad. In view of the direct findings with *Tom*, therefore, we must advocate the nitrogen-stimulation theory with a certain degree of caution.

The picture presented by these men on reduced diet is similar in certain ways to that noted with diabetics who have been undergoing the Allen fasting treatment. Prior to the Allen treatment the metabolism is very high, being on the average 15 to 20 per cent higher than that of normal individuals of equal height and weight. Following the Allen treatment the metabolism becomes very much reduced. Not only does it fall to normal, but is actually lower than that of normal individuals of the same height, weight, and age. The dietetic régime of the

[1] It should be noted that these figures are for the entire period of the experiment, while those in table 71, p. 351, do not include the last week.

diabetic, together with the course of the disease, almost invariably results in a great loss of fat and not a little nitrogenous tissue; hence we believe that the loss of nitrogen as well as loss of flesh in the diabetic contributes towards this lowered metabolism after the cellular stimulus of acidosis has been removed by the Allen fasting treatment.

CALORIC REQUIREMENT FOR WEIGHT MAINTENANCE.

In the discussion of the caloric intake at weight maintenance (see p. 283), emphasis was laid upon the fact that if the body-weight were held at a constant level for a sufficient length of time (probably months rather than weeks), the net caloric intake could be rationally taken as a measure of the caloric requirement.

Certain difficulties were experienced in finding sharply marked periods of body-weight maintenance covering a considerable length of time in this series of tests, and in no other phase of the research do we regret more the necessity for the uncontrolled period during the Christmas recess. There were, however, two periods of reasonably constant weight which appear on the several charts for Squad A. From an inspection of these data we inferred that weight maintenance at the lower level was held with net calories ranging from 1,600 calories for *Kon*, *Pec* and *Tom* to 2,500 calories for *Can*. The average for the squad was approximately 1,950 net calories. Since the intake prior to diet restriction was somewhat over 3,000 calories, and Squad B, living under substantially the same conditions aside from diet, required nearer 3,800 calories, it can be seen that the diet for Squad A at these periods of weight-maintenance was a reduction of from one-third to nearly one-half of the normal diet.

Emphasis must be laid again, however, upon the fact that the body-weight is an extremely unsatisfactory and indeed crude index of caloric needs, unless maintained for a much longer period of time than was possible in these experiments. Recourse was had, therefore, to other criteria.

BASAL GASEOUS METABOLISM.

From two entirely independent types of respiration experiments certain fundamental data were available to show profound alterations in basal metabolism of all of these subjects following the reduction in diet. These reductions in basal metabolism were not only absolute—that is, each member of the squad had a basal metabolism very much lower at the end of the experiment than at the beginning—but they were likewise relative, for the basal metabolism on both of the two usual comparison bases, namely, the heat production per kilogram of body-weight and per square meter of body-surface, showed reductions approximating 15 to 20 per cent. On the more logical method of comparison of the basal metabolism with the predicted values from a series of tables based upon an extensive study of normal data obtained in this Laboratory, it would likewise seem that whereas these men at the

beginning of the experiment showed a normal basal metabolism perceptibly higher on the average than that predicted for men of equal weight, height, and age, at the end of the test they all showed strikingly lower values than the predicted values from the analysis of a large group of normal people. Under the circumstances, therefore, the evidence is clear that the reduction in basal metabolism is a real one. The fact that the body-weight index implied a maintenance caloric requirement over one-third or nearly one-half that prior to diet reduction, while the gaseous metabolism suggests a lowering approximating only 15 to 20 per cent, is somewhat difficult to explain other than on the ground that the body-weight data used for comparison were for altogether too short a period. From an analysis of the chart it can be seen that the influence of the reduced diet on all factors was a progressive one, with a rather rapid effect shortly after the reduction in diet began, and a tendency towards constancy coincident with constancy in body-weight.

Emphasis throughout this entire monograph has been laid upon the basal metabolism. We have not infrequently been taken to task by thoughtless critics of previous reports, who have maintained that the basal metabolism should be expressed only in periods of minutes or hours, and the length of time for which it should be expressed is determined solely by the length of the experimental period upon which the measurement is made. In the last analysis the basal metabolism of a given individual is the most important factor in his energy transformations for the 24 hours. If this is once known, the superimposed values for activities greater than lying are readily and with reasonable accuracy computed. It thus becomes of special interest to compute the probable daily caloric requirement of this group of men at the end of their diet test. For this purpose we have computed the values for the last 3 days and give the results in table 202. From this it can be

TABLE 202.—*Calculation of probable average heat output per 24 hours during last three days of experiment—Squad A.*

	cals.
Basal heat per 24 hours (computed)[a]	1,367
"Cost of digestion" (2,486 cals.[b] $\times$ [c]0.06)	149
Heat output due to sitting ([d]11 hrs. $\times \frac{1367}{24} \times$ [e]0.10)	63
Heat output due to walking ([f]6.7 miles $\times$ [g]56)	375
Heat output due to exercise greater than walking ([d]1 hr. $\times \frac{1367}{24} \times$ [e]4.00)	228
Total	2,182
Average net calories per day[b]	2,245

[a]See table 128.
[b]Computed from tables 46 to 58.
[c]Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918, p. 343.
[d]Computed from table 194.
[e]Increase in heat output above basal for exercise greater than walking and for sitting assumed to be 400 per cent and 10 per cent respectively.
[f]Computed from daily records of walking (pedometer).
[g]Heat output above basal per mile of level walking; computed from data in tables 142 and 128.

seen that the basal heat per 24 hours was 1,367 calories. On these days there was an average gross intake of 2,486 calories. It has been found by Dr. T. M. Carpenter,[1] of this Laboratory, in recent extensive research, that an average figure for the excess heat resulting from the ingestion of mixed diet is 6 per cent of the gross energy intake. This may be stated to be the "cost of digestion." Under these conditions 149 calories represents the "cost of digestion" for this period.

As outlined in previous sections, the basal metabolism assumes the individual to be lying down without food in the stomach. The extra heat due to the ingestion of food has already been accounted for as "cost of digestion." From the carefully kept records of these men, the number of hours during which they were sitting has been recorded and averages 11 hours for these 3 days. While many writers ascribe no value to the difference between lying and sitting positions, particularly if the subject be carefully adjusted in a steamer chair, it seems reasonable to consider 10 per cent as a probable factor for the increase in the metabolism, this being substantiated by a large amount of experimental evidence.[2] The per hour figure for the basal value is 57 calories; 10 per cent of this value, multiplied by 11 hours, will therefore give 63 calories for the extra heat output due to the sitting position.

From the pedometer records these men showed an average mileage of 6.7 miles per day for the 3 days (January 30 and 31 and February 1). Extensive data on the energy requirements for horizontal walking, secured in the treadmill experiments (see p. 533) give accurate figures for computing the average caloric requirement for walking 1 mile. It has thus been found that the extra energy above basal for walking 1 mile would mean, at this stage of the diet restriction, 56 calories. This multiplied by the daily mileage of 6.7 miles equals 375 calories for the activity of walking.

In addition to the walking, the men reported on the average about 1 hour exercise more active than walking. With this factor we must make several rather debatable assumptions. An examination of the protocols shows that the men not infrequently included in this exercise certain of the simpler gymnastic exercises, such as were shown in the moving pictures, etc.; also other work which usually calls for severe work for short periods but relatively long periods of rest. These activities were recorded as work greater than walking. It seems to us reasonable to assume for this exercise an increased output of heat above basal amounting to 400 per cent. The basal value was 57 calories per hour; 400 per cent of this for 1 hour would therefore amount to 228 calories.

[1]Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 261, 1918, p. 343.

[2]Emmes and Riche, Am. Journ. Physiol., 1911, **27**, p. 406; also Soderstrom, Meyer, and Du Bois, Arch. Intern. Med., 1916, **17**, p. 872.

We thus have a total energy output, computed on this basis, of 2,182 calories. The element of greatest uncertainty in the whole computation is admittedly the last factor, namely, the energy due to exercise greater than walking. Possibly, also, the increase above basal due to the sitting should be somewhat greater than it is, for one can conceive of students giving off a very considerable amount of heat when sitting and gesticulating. A recent series of experiments at the Nutrition Laboratory with several groups of Simmons College students has shown that reading aloud has a strikingly small effect upon the quiet resting metabolism, so we are inclined to think that our figure of 10 per cent is not far from correct. A comparison of this total figure of 2,182 calories with the average net calories in the diet for these 3 days (2,245 calories) is of interest. This agreement is in all probability a fortuitous one, as it would assume a long-established body-weight, which previous discussion has shown was not actual, especially on these last few days. We introduce this method of calculation, however, in part to illustrate the great significance of an accurate knowledge of the 24-hour basal requirement as the foundation for computing the probable daily heat output.

From the gaseous-metabolism measurements, therefore, which show a profound reduction in the basal metabolism on the two different types of apparatus and from the dietetic intake as calculated from the net calories, it is clear that the energy requirements of these men were very much lower at the end of the experiment than they were at the beginning with normal diet. A computation of the probable dietetic requirements of these men during the last three days of the diet seems to substantiate fully the inferences drawn from the other criteria, and it is quite clear that these men were subsisting upon a diet fully one-third less than that normally required. The full significance of this, however, lies not so much in the fact that there was an actual reduction of one-third, but that it implies distinctly that there must have been a proportionately great reduction of the energy demands for work other than the basal maintenance. The results obtained in the treadmill experiments showed clearly that the energy for forward progression, *i. e.*, the amount of energy required to move 1 kilogram 1 horizontal meter was appreciably lower when the men were on restricted diet than with normal diet. In connection with that discussion it was pointed out that although we could speak with certainty only of this particular type of muscular work, yet we have every reason to believe that the same efficiency of muscular coordination would obtain with other types of muscular work. This suggests a greatly lowered energy requirement for all of the activities of the day not merely in the lying position and post-absorptive condition, nor only when walking on the treadmill, but likewise in all the extraneous activities entering into the daily life.

PRACTICAL CONSIDERATIONS.

As a result of the extensive scientific findings recorded in the several chapters of this discussion, this research as a whole, we hope, makes some important contributions not only to abstract science, but certain of the data supply legitimate bases for practical use in periods of stress such as obtained during the recent world war. The fundamental possibility of completely lowering the nutritional level so as to produce profound alterations in the gaseous metabolism, blood pressure, pulse, and practically all physiological functions opens a new field for the study of physiology at a low nutritional level. The fact that the whole picture was presented with striking clearness by Squad B after a relatively few days of low diet makes it not only possible but practicable to duplicate the experimental conditions easily and to refine the study of any one of the many scientific problems presented by this research. Several of these have already been indicated in our text. We regret particularly not having secured some evidence with regard to the stimulating effects of foodstuffs at this lower level, for such study should contribute materially to an explanation of the cause of the excess heat production following food ingestion. It is not impossible that many factors which are now studied on the normal nutritional level would be considerably accentuated by being superimposed on the lower level. A complete study of the character of the blood nitrogen is of course imperative. Further and more intricate studies of pulse and blood pressure, and their reactions to posture and both moderate and severe work, should also prove profitable lines of study.

Without attempting to catalogue any considerable number of these abstractly scientific problems, we would call attention to the possibilities of the therapeutic use of this procedure, since we have here two pronounced factors which are popularly supposed to influence perturbed metabolism. One of these, the removal of an excessive amount of nitrogen by the simple method of producing undernutrition, should have most important bearings upon many pathological conditions. Second, the profound lowering of the total metabolism, which has already been found in the Allen fasting treatment for diabetics to have great therapeutic effectiveness, will doubtless be extended to other pathological cases. These are problems primarily for the clinician. The dietetic procedure is extraordinarily simple, is in no particular sense strenuous or painful, and the condition of lowered nitrogen and lowered metabolism can be rapidly produced in a few weeks. The untoward influence of both procedures upon norma' healthy man is so slight as to indicate that danger, if any exist, must be remote. The beneficial effects in many pathological cases of removing large amounts of surplus nitrogen and of lowering the metabolism perceptibly will, it is confidently believed, be demonstrated in the near future.

The loss in weight of all of our subjects was a resultant of the restricted diet and the relatively active daily program. After the short periods of excess food on the free Sundays or holidays, the loss in weight was accentuated by severe physical exercise. The reduction in body-weight primarily by excessive physical exercise is also a problem that, in the light of the present research, assumes new significance; a complete interpretation of the physiology of weight reduction can not be made unless this factor has been thoroughly tested. A practical application of the principles laid down in this research may be found, however, in the question of moderate reduction cures. With the weight reduction produced by these men, either absolute or percentagewise, no serious physiological effects were noted. A word of caution, however, should be inserted, for, as McKenzie[1] has pointed out, weight reduction without accompanying physical exercise is liable to cause a loss of bodily power; furthermore, in connection with the loss of protein, when loss of weight is produced without due regard to keeping up the general tone of the body by muscular activity, constipation, hernia, and gastroptosis, particularly in middle-aged and excessively fat women, may occasionally occur. Although the rapid absorption of fat has occasionally caused displacements of the kidneys and uterus, the resulting symptoms have usually not been more troublesome than the obesity itself. For moderate weight reductions of 10 per cent it is safe to predict that even such rare occurrences may not be noted. Further weight reduction should be carried out only with the constant supervision of a competent physician.

Entirely aside from the laboratory and clinical suggestions arising from this research, we should consider the influence of an observation of this kind upon the feasibility of general dietetic restrictions as a food-conservation measure. Judging superficially from the appearance of these men at the end of their long period of restricted diet and from the amount of their intellectual and physical activity, one could assert almost with certainty that a reduction of total caloric intake of one-third was an assured possibility. Certain objections to this have been cited in our discussion. Of these the picture of secondary anemia indicated by the blood findings, the marked repression of all normal sex expression, the mental unrest and dissatisfaction experienced by many of these men should all be seriously considered. Dr. Minot believes that the anemia would not progress much farther with continuance of this diet. The absence of sex interest has an important bearing on the subject of the propagation of the race. It is possible that nature is insistent that the metabolic level found in practically all normal individuals is that best adapted for propagation and that reduction in this level can only be made at a sacrifice of sex interest and

[1]McKenzie, Exercise in Education and Medicine, Philadelphia, 1915, 2d ed. p. 530.

reduction of propagation. These warnings must certainly be heeded. Precisely the same factors that reduced normal sex expression in these men may, however, be of extreme practical importance in pathological phases of sexual perversions.

The introspection shows clearly that not a little of the mental unrest was caused by the fact that others were eating liberally and freely and the social element was removed or repressed.

Certain possible procedures that in times of stress might be justifiably recommended, at least as war measures, have been considered recently in reporting some of the data from this research.[1] This is not the place to enter into any discussion of the practical application of these diets to immediate economic national problems. It is, however, perfectly justifiable to make conclusions as to the practicability of a reduced diet in food stringencies. Entirely aside from war or any factors pertaining thereto, food stringencies will inevitably occur throughout the world as a result of accident, floods, climatic disturbances, etc. To instill into the world at large a belief that a pronounced lowering of rations is not necessarily accompanied by a complete disintegration of the organism and collapse of mental and physical powers may, after all, be of real service. A reduced ration may be a minimum, but this is far from saying that it is an optimum. Experimental evidence has accumulated in sufficient amounts to justify a serious consideration of a material reduction in the intake of protein, which is one of the most expensive factors in human food. It is not clear that a low-protein diet is harmful. Indeed, much of the evidence now points to the fact that a low-protein diet is without harmful effects upon the organism.

One of our unsolved problems in this research is the relationship between body protein and metabolic level. If the lowered general metabolism is due to the absence of protein in the body—and our evidence points strongly towards this—we may then argue that while in times of stress the minimum and lower level is justifiable and reasonably safe, in times of plenty the optimum is a higher protein level. The reduction of body-weight without loss of body-nitrogen is a scientific situation that should be thoroughly investigated. Our data throw no light on this subject. Obviously the diet could be so adjusted as to keep up the supply of body-nitrogen for the most part and still draw from body-fat. Until experiments of this type are made with accuracy and in sufficient numbers to settle this question without doubt, the amount of the optimum protein intake must be held in abeyance. For a tentative war measure the question of low protein need not seriously be contested. The recent marvelous developments as a result of the study of the so-called "food accessory substances"

[1] Benedict, Proc. Am. Phil. Soc., 1918, **57**, p. 479.

lead us to believe that instead of devoting an undue amount of time to fictitious "nitrogen balances" and an attempt to curtail nitrogen to an extraordinarily low point, the character of the nitrogenous material ingested, including the food accessories, should be carefully considered, and then and not until then can the ultimate reduction of protein be properly studied.

In connection with the study of low protein and the value of the surplus protein of the body, a complementary condition should be studied in which, after the reduction in protein and its concomitant body-loss, there should be realimentation with low nitrogen intake to minimize nitrogen storage but accentuate the return to normal weight. Under these conditions the true value of the nitrogen storage to the body would be clearly shown. Furthermore, the level of nitrogen equilibrium on a diet with very low nitrogen and the normal calories for weight maintenance should be established and carefully explored. For all practical purposes, however, it is clear that the so-called low-protein diet is perfectly justifiable as a war measure and in all probability is a logical procedure that can not be accompanied with any untoward effects, even by long-continued practice. Just what this level should be remains to be demonstrated.

Our evidence seems to show that, at least with American young men, the nitrogen excretion in urine is much lower than has been commonly supposed. Whether this speaks for a nitrogen metabolism that has always existed, or whether it is due to the fact that the agitation for low protein has been gradually impressing itself upon the American dietetic habits, we can not state. A nitrogen excretion with normal men of 9 grams of nitrogen, *i. e.*, 0.15 gram per kilogram of body-weight, is a minimum level certainly well above any danger-line.

We may say, in summarizing, that protein curtailment is an assured and physiologically sound procedure, and a reduction in calories is possible for long periods, but definite and significant disturbances of blood composition, normal sex expression, and neuro-muscular efficiency, and the appearance of mental and physical unrest are deterrent factors in too sweeping generalizations as to the minimum calories being synonymous with an optimum level.